TAMPERE UNIVERSITY OF TECHNOLOGY

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IMPLEMENTING BUILDING INFORMATION MODELING (BIM) IN PRECAST FABRICATION USING A RE-ENGINEERING METHODOLOGY

Master of Science Thesis

Assoc. Prof. (tenure track) Marko Seppänen has been appointed as the examiner at the Council Meeting of the Faculty of Business and Built Environment on April 8th, 2015.

ABSTRACT

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This thesis examines how Building Information Modeling (BIM) could be implemented more efficiently to structural precast fabrication process. The goal is to create an efficient BIM implementation process and a basic guideline that are customized to meet the needs of structural precast fabricators. At the moment neither the aforesaid process nor a guideline exists, and this has led to diverse results regarding BIM implementation efforts.

The literature review was carried out in two parts: first through conducting a comprehensive literature review regarding BIM. Results of the first literature review were complemented with a second literature review regarding Business Process Re-engineering (BPR). Literature reviews formed the theoretical foundation that was then reviewed against the findings of case interviews.

Based on the empirical findings from both literature reviews and the case interviews, the BIM implementation process for structural precast fabricators and the guideline on how to execute and follow up the progress of the implementation were created. The process as well as the guideline consists of various process phases and parts of BIM.

The main theoretical contributions are the BIM implementation process and the guideline that were developed through combining the theories of BIM and BPR. As a practical contribution, some tools for the process and the guideline were developed or modified to facilitate BIM implementation efforts.

TIIVISTELMÄ

TAMPEREEN TEKNILLINEN YLIOPISTO
Tuotantotalouden koulutusohjelma

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Tässä diplomityössä tutkittiin, kuinka tuotemallinnusta voitaisiin tehokkaammin ottaa käyttöön runkorakenteina käytettävien betonielementtien valmistusprosesseihin. Päätavoitteena oli kehittää toimivat BIM-käyttöönoton prosessi ja ohjeistus, jotka vastaavat erityisesti runkorakennebetonielementtivalmistajien tarpeisiin. Tällä hetkellä edellä mainittua prosessia tai ohjeistusta ei ole olemassa, ja tämä on johtanut hyvin vaihteleviin tuloksiin BIM-käyttöönotoissa.

Diplomityössä toteutettiin laajamittainen kirjallisuuskatsaus tuotemallinnuksesta. Sen tuloksia täydennettiin toisella kirjallisuustutkimuksella liiketoimintaprosessien uudelleenjärjestelyn (Business Process Re-engineering, BPR) teoriasta. Kirjallisuuskatsaukset muodostivat diplomityön teoreettisen viitekehyksen, jota tarkasteltiin kohdeyrityksien haastatteluista saadun kokemusperäisen tiedon valossa.

Kirjallisuuskatsauksista ja kohdeyritysten haastatteluista saatujen havaintojen pohjalta kehitettiin tuotemallinnuksen käyttöönottoprosessi ja ohjeistus siihen, kuinka toteuttaa ja seurata käyttöönoton etenemistä, erityisesti runkorakenteena käytettävien betonielementtien valmistuksessa. Prosessi sekä ohjeistus koostuvat eri prosessivaiheista sekä BIM-osioista.

Diplomityön tärkeimmät teoreettiset tuotokset ovat BIM-käyttöönottoprosessi ja ohjeistus käyttöönottoon, jotka kehitettiin yhdistelemällä BIM- ja BPR-teoriaa. Diplomityön käytännön tuloksena kehitettiin ja räätälöitiin eri työkaluja helpottamaan sekä BIM-käyttöönottoprosessia että ohjeistuksen käyttöä.

PREFACE

The topmost feeling after finalizing this thesis is relief, since this thesis represents the ending of a long journey that started in Pori in autumn 2008. Many things have happened since that; a house and apartments have been renovated, employers and job descriptions have changed, and children have been born. All in all, this thesis closes a sort of life chapter, and now it is time to choose new direction and goals.

There are a number of people who have helped me pave the way to status quo. The most important person during this whole journey has been my wife Nora, who has given me the time and support that was needed to achieve this. I would like to thank my dear colleague Jarmo Manninen for the continuous push, support and discussions that have kept me going forward, as well as my parents and mother-in-law, who have given the additional support when needed. Special thanks also to Prof. Marko Seppänen; without his valuable advice and comments this thesis would not have been the same.

Finally, I would like to dedicate this thesis to my daughters Siiri and Elli, as nothing will ever compensate the time that we have lost while writing this thesis.

Onward to new challenges, in Helsinki May 11th, 2015.

Antti Soikkeli

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ABBREVIATIONS AND NOTATION

2D	Two dimensional: x- and y-axis
3D	Three dimensional: x-, y- and z-axis
AEC	Architecture, Engineering and Construction
AECO	Architecture, Engineering, Construction and Operations
BIM	Building Information Modeling
BPR	Business Process Re-engineering
CAD	Computer-aided Design
ERP	Enterprise Resource Planning
IPD	Integrated Project Delivery
IT	Information Technology
MIS	Management Information System
NBIMS	The National BIM Standard
nD Modeling	In nD Modeling n represents the number of dimensions that are being modeled. When for example time is added on top of the three traditional dimensions, the process is called 4D Modeling, and if cost is also added, it is called 5D Modeling.
NIBS	National Institute of Building Science
MRP	Material Requirements Planning
Parametric modeling	In parametric modeling, parameters may be modified later and the model will update to reflect the modification.
PCSC	Precast Concrete Software Consortium
SaaS	Software as a Service

1. INTRODUCTION

This chapter presents a background for this study and discusses the research questions and objectives. In addition, it presents the research methods as well as an outline for the rest of this study.

1.1. Background

Since 2008, global construction industry has been suffering from the economic situation, especially in the Western Countries, but even so, there has been an upsurge in the use of product models in the construction industry in the last decade (Young et al. 2008; Young et al. 2009; Epstein 2012; Jones & Bernstein 2014a). While governments and central banks have tightened their economic policies, also companies in the construction industry have started to tighten their own policies, and possible savings easily raise the management's interest. So far the construction industry has been searching for cost savings through more efficient production methods. Studies have revealed that the productivity of the construction industry has been the same for the last five decades, while other non-farm industries have more than doubled their productivity (Eastman et al. 2011, pp.10-11). Figure 1.1 illustrates how other non-farm industries have been improving their productivity since 1964.

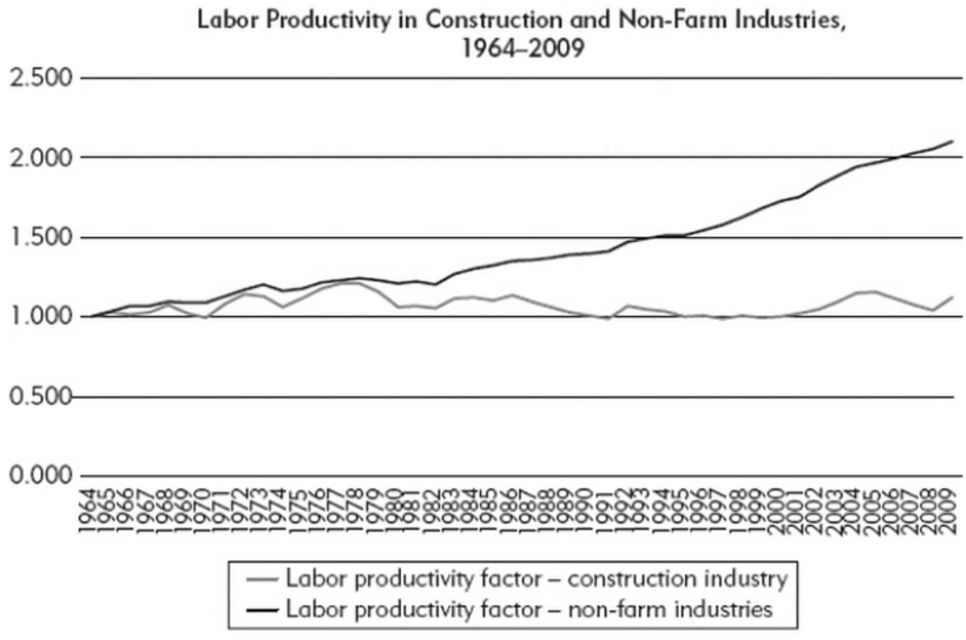

Figure 1.1 Indexes of labor productivity for construction and non-farm industries in the United States between 1964 and 2009. The data was calculated by dividing constant

contract dollars by field worker-hours of labor for those contracts. (Eastman et al. 2011, pp.10−11)

One of the main reasons for this is the fact that the non-farm industries have been able to utilize the benefits of new technologies, and they have been able to automate some tasks in the process or even whole processes. However, non-farm industries have also been bolder to discover the opportunities that new technologies offer to increase productivity. When automobile, airplane, electronics and consumer goods manufacturers faced global competitive pressure, they turned to model-based digital design processes that supported engineering, bill-of-materials, cost modeling, production planning, supply-chain integration and eventually computer-driven fabrication on the factory floor (Bernstein & Pittman 2004). Another possible reason for the gap might be the fact that companies in the construction industry invest very little in research and development. According to Andresen et al. (2000), it is typical that research and development is underfunded in construction companies (Andresen et al. 2000 see Sacks et al. 2005).

For decades companies, industry experts and academics have been trying to find solutions to this problem of productivity. So far the solutions offered to improve productivity have only meant fine-tuning the existing process or trying to embed various IT-solutions on top of existing processes. Various product innovations, like gypsum board, are examples of the ways by which the construction industry has been able to decrease manual work on site and various Computer-aided Design (CAD) software products are examples of decreasing the manual work of an engineer, but actual engineering and design work still consists of just drawing lines, which is still the same job that was done earlier on a drawing board. So far, these kinds of solutions have not been able to offer the radical improvements that other non-farm industries have achieved.

In the beginning of the 1990s some academics suggested that the construction industry could improve its productivity through a product model of the building (Eastman 1992, pp.107−109). The reason for this was simple. All other industries have already shifted to product models, which has enabled them to automate manual work. After these kinds of findings industry experts and academics started to explore the opportunities and limitations of product models in the construction industry (Jung & Joo 2011; Succar 2009).

In many manufacturing industries, drafting has been removed from the use of CAD-based solutions in 3D product modeling, which supports automation and quality control applications that utilize the generated information (Sacks et al. 2004, p.292). The level of automation has also increased significantly in the building-product industry during the last century. Although 3D product-model information is not utilized in downstream activities, which leaves a major part of the model information's value in the project life cycle unrealized (Aram et al. 2013, p.2). Product modeling offers potential parallel benefits for the construction industry: the use of knowledge-based design tools, automated detailing and drawing production, automated interfaces to structural analyses, and quality improvements (Sacks et al. 2004, p.292). Product Model, Virtual Building™, nD Modeling, Building Product Models and Building Information Modeling (BIM) are some names that have been using for product models in the construction industry during recent decades (Succar 2009; NBIMS 2007).

At the moment the construction industry is on the edge of change, since some companies have been using product models as a part of their process for a while. Probably the best example of this is the steel industry where product models were in use already in the mid-nineties (Lee et al. 2006; Sacks et al. 2004; Eastman et al. 2003). This has greatly improved productivity of steel fabrication, since companies have been able to increase the level of automation on the shop-floor level with the data from product models. During the last decade also other building-product industries have begun to move towards product models forming a part of their design and fabrication processes.

The implementation of product models has taken much longer than has been expected (AIA 2007). Rough estimate is that only the innovators, early adapters, and some of the early majority have implemented product models into their processes. This means that the vast majority of the construction industry is still working using paper-based processes based on centuries-old traditions. Because of this, some of the academics and industry experts have started to study the problems of product model implementation (Gu & London 2010, p.988). Early findings of these studies indicate that companies in the construction industry should pay more attention to the implementation of product models, since the implementation usually creates bigger changes in a company’s infrastructure and processes than anticipated (Kaner et al. 2008, p.305).

One commonly held assumption why the implementation of product models has been delayed is due to the fragmentation of the construction industry. Traditionally the industry has been craftsman-oriented so that small companies carry out only a few steps of a complex process and come together to execute projects in a very competitive setting, with each project typically involving a change of participants (Eastman et al. 2002, p.2). According to the American Institute of Architects (2007, p.21) and Epstein (2012, p.51), another possible reason for the delay of product model implementation might be the fact that product modeling shifts the design work effort in the whole construction process. Figure 1.2 demonstrates how the designers' work effort progresses during a construction project both when using traditional paper-based design process and when using the new product model-based process. All of these implications lead to a situation where no single participant and no single project have enough economic impact to justify the investment to convert to knowledge-based product models (Eastman et al. 2002, p.2).

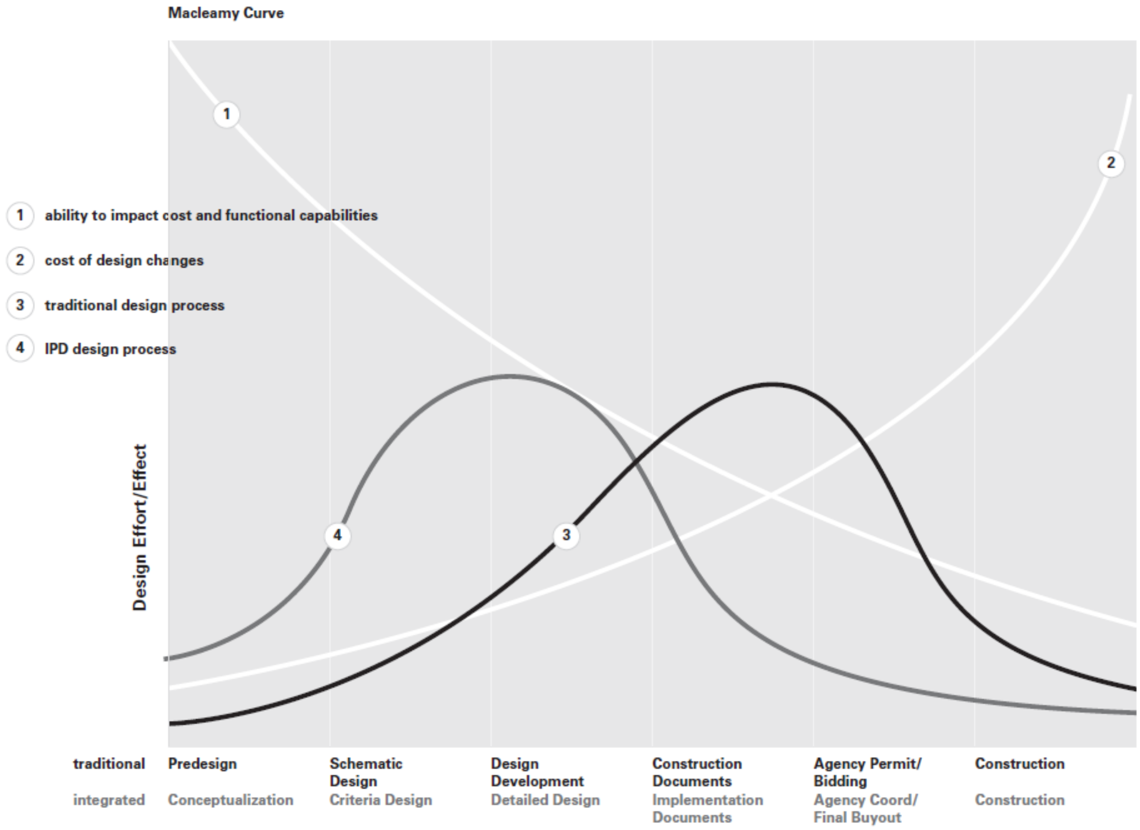

Figure 1.2 The "Macleamy Curve" illustrates the concept of making design decisions earlier in the project when the opportunity to influence positive outcomes is maximized and the cost of changes is minimized (AIA 2007).

This relatively small change has hugely impacted the traditional way of working in the construction industry. This means that all project parties have to take part in the process much earlier since all the design decisions have to be done in an earlier phase of the project. This small demand enables more cost-efficient way of working where changes can be handled during earlier phases of the process when they are still affordable to execute. Several studies have also proven that product models have brought clear benefits to the companies in the construction industry (Hannon 2007; Eastman 2009; Becerik-Gerber & Rice 2009; Sacks et al. 2005; Eastman et al. 2006).

1.1.1. Motivation of the study

Steel industry's successful implementation of product models has raised similar interested in the other parts of the construction industry. Especially companies in the prefabricated concrete industry (later precast industry), who are many times competing against the companies in the steel industry, have been trying to implement product models in their processes, but the results and benefits gained are not at a similar level. According to

Eastman et al. (2003, p.249), one reason for this might be the fact that precast industry has unique engineering and software needs.

When companies in the precast industry have decided to move towards product models, the implementation period has usually been long and the companies have not achieved the goals they had set in the beginning. Precast companies have faced the same issues during implementation all over the world, and it also seems that these problems are not software-specific, but more like industry-specific. Some of the academics and industry experts have already tried to solve the problems of product model implementation for precast companies, but so far the results and guidelines have been at very general level (Kaner et al. 2008, pp.303−323).

The basic fabrication principles of prefabricated precast concrete products and prefabricated steel products are quite similar. The only significant difference between these two industries is the fact that companies in the steel industry are working with very standardized products and dimensions whereas almost every company the in precast industry has their own standard products. This should not be a problem since other industries have managed to achieve higher productivity and a more efficient way of working with batch size one.

There is no clear guideline or process to help precast companies in implementing product models successfully and in a tolerable period. Previous studies have concentrated on describing the implementation process at a very general level (Maunula 2008; Succar 2009; Succar 2010; Coates et al. 2010; Gu & London 2010; Jung & Joo 2011; Pickup 2013), on the technical details of implementation (Succar et al. 2012; Succar et al. 2013), or on very specific topics like how to use or create model information (Laine 2008; Mäläskä 2011; Häkkinen 2012; Tuikka 2012; Haavisto 2013; Niskakangas 2014). Few studies have focused on actual building-product fabrication or how to implement model information in the building-product fabrication process. Software vendors have tried to solve this problem by offering various training programs and consultation services to support the technical part of software implementation. It seems that these kinds of programs and services have not been working, since precast companies are not achieving their goals, or if they have achieved the goals, the period to do so has been far too long. Some of the companies have not seen the value of training or consultation services and have tried to learn the software by themselves. It seems that some of the precast companies have gained successful implementation results by self-learning, but most of the companies face even bigger problems when trying to solve problems by themselves.

1.1.2. Framework of the study

This study will approach product models from a Building Information Modeling (BIM) theoretical point of view. Theory and analysis of the software implementation process concentrate only on the implementation of BIM software and not for example on two-dimensional computer-aided design software. Because of precast industry's unique nature within the construction industry, this study only focuses on the implementation process in the precast industry. Usually the precast industry is separated into two categories: 1) companies fabricating precast elements for infrastructural purposes, for example curbs and sewer pipes, and 2) companies fabricating structural precast elements for building purposes, for example hollow-core slabs and sandwich panels. This study will focus on the companies fabricating structural precast elements for building purposes. Typical structural precast elements can be seen in Figure 1.3.

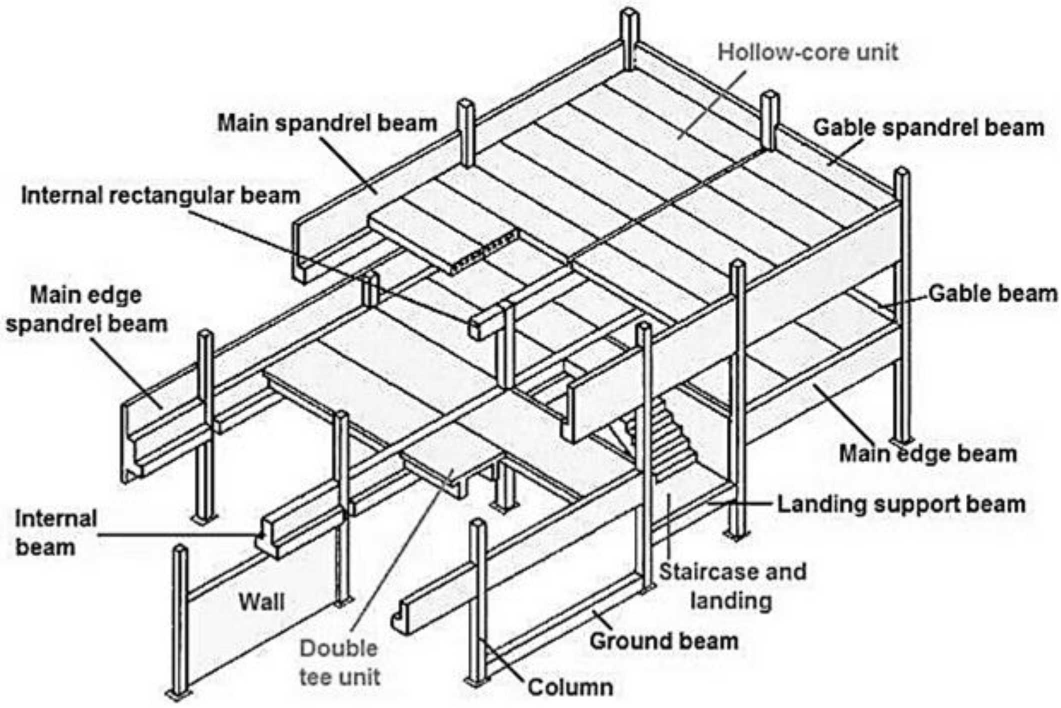

Figure 1.3 Most commonly fabricated structural precast elements (Mishra 2014).

Companies that fabricate structural precast elements can be roughly divided into three categories based on their size and activities. Each of these three categories, which are small local companies, mid-sized regional companies, and large global corporations, has its own special characteristics that need to be taken into account in the implementation. This study strives to cover all of these three categories.

Based on the BIM literature review, this thesis presents a literature review on Business Process Re-engineering (BPR) for the implementation process. Another issue that emerged in the BIM literature review was change management. This thesis does not focus on the change management topic itself but concentrates on developing the right kind of implementation process that at some level takes into account change management.

1.2. Research question and objectives

The precast fabricators that have decided to invest in BIM have faced surprisingly many setbacks when trying to implement BIM in their daily routines. This study attempts to cover this problem and strives to find the key steps to help companies pursue successful implementation. The research question is: *How to make BIM implementation more efficient for the structural precast industry?*

In order to make implementation phases more efficient, this question is tackled from the perspective of improving processes and guidelines. The unique nature of precast fabrication has to be taken into account and the fact that there are typically three kinds of fabrication companies. Three sub-questions were posed:

1. *What kinds of sub-phases enable an efficient implementation process?*
2. *What kinds of competencies are needed from individuals and organizations during the implementation?*
3. *How to follow up on the progress of implementation?*

Thus, the main objective of this study is to develop a BIM implementation guideline for the structural precast industry. This guideline should help firms implement BIM in their systems more efficiently and faster. The guideline itself should be built from modules, meaning that its phases should function independently, as every fabricator may not want to or have the resources to re-engineer all of their processes during the BIM implementation.

In addition, this study strives to find the tools that enable fabricators to follow up on the progress of implementation. These tools need to be simple and suitable for the structural precast fabricators, and they need to take into account the unique nature of the structural precast industry. The tools are designed according to traffic-light principle; if the indicator is green, it is possible to move forward; if it is yellow, some additional efforts are needed; when the indicator is red, implementation cannot proceed until existing issues have been fixed.

1.3. Research methods

Two most common research methods are hermeneutics and positivism (Olkkonen 1993, p.26). Since this study strives to find a solution based on both the understanding of the researcher and interviews made in target companies, the chosen research method is hermeneutics. Furthermore, hermeneutics is used in this study to examine the different phases of development and what is happening in the surroundings at the same time (Olkkonen 1993, p.33).

The research method was not clear in the beginning of this study. Because of this, it was decided to start with a comprehensive literature review of product models in the construction industry. After a comprehensive literature review, which provided much more understanding about product models and their implementation in the construction industry, it was easier to perceive the problem and the research methods to use in this work. The research problem itself also became much clearer, and an implementation guideline was defined based on the findings. This increased understanding of the research problem, and the theories led to the second literature review as well to case study interviews of target companies, and the research method was specified to be action-analytic research method.

In this study, structural precast fabricators have been divided into three groups, and one representative sample company was chosen from each of these groups for the case company interviews. Chosen fabricators were contacted and interviewed. Interviews were performed with one or two individuals from each company. These individuals had personal experience from implementation because all of them had been in a key position when their companies were implementing BIM in their processes. The main purpose of the interviews was to collect empirical data that could be used later during research. At the same time, another extensive literature review was conducted on Business Process Re-engineering (BPR). The BIM implementation guideline was then reshaped with findings from the second literature review.

1.4. Outline of the study

This study is divided into four sections; introduction (section 1), literature reviews (section 2), research approach (section 3) and results (section 4). This first section introduces the research work in its entirety excluding results and conclusions. The second section presents both literature reviews. Extensive literature reviews were performed on two subjects: BIM and BPR. The literature review on BIM concentrated on journals, articles and white papers from both academics and industry experts, because BIM is a relatively new topic and there are not many printed publications available. The first step in the BPR literature review was to obtain basic understanding of the theory and how it has been studied by academics.

The research approach is presented in the third section. After introducing the research setting, this thesis presents a general introduction to the precast industry and the three case study companies interviewed. The research methodology is presented in the end of this section. The fourth, final section summarizes the findings of the research work. This section is divided into two parts: the empirical findings and the conclusions. The fourth section introduces the results from both interviews and literature reviews and proves the evidence of the research.

2. PRODUCT MODELS IN THE CONSTRUCTION INDUSTRY

According to Eastman et al. (2002, p.429), product models have become common information technology artifacts. Product models are able to bring both direct (reduced design and drafting costs, enabling production automation, etc.) and indirect (reduced error rates in construction, enhanced ability to consider design alternatives, etc.) benefits to the construction industry (Sacks et al. 2004, p.309). Although the benefits are evident, most of the companies in the construction industry are struggling with the implementation of product models. One of the reasons for this is that an implementation done thoroughly affects most of the activities inside the company. As seen in Figure 2.1, Porter (1998) has divided a company's activities into Primary Activities and Support Activities.

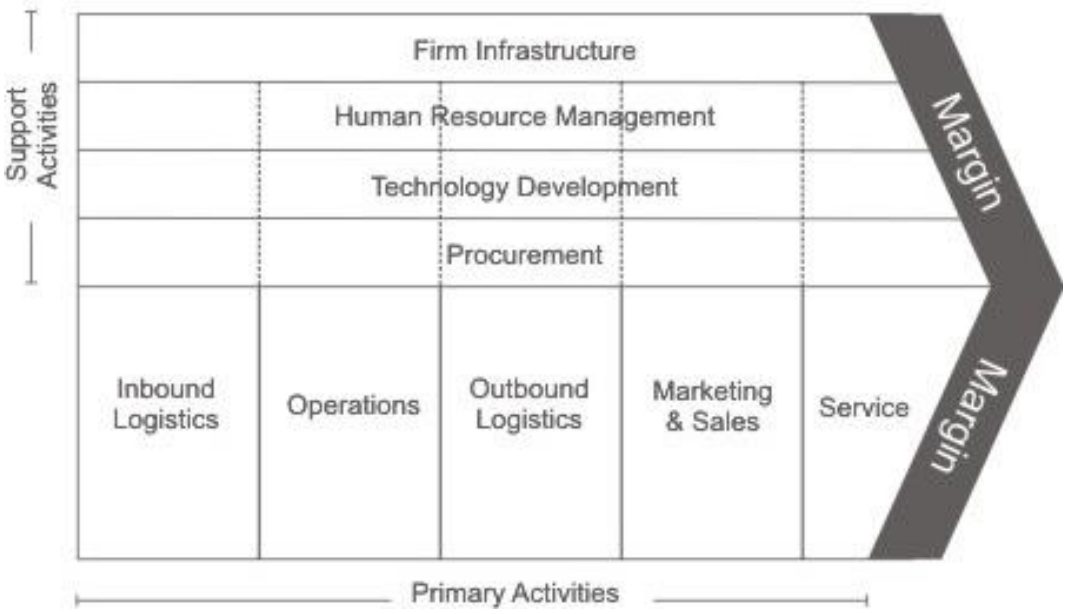

Figure 2.1 Porter's Generic Value Chain (Porter 1998, p.37).

Implementing product models thoroughly in the construction industry will have immediate impact on the Primary Activities of the companies but models will also affect every Support Activity in a later phase of implementation. Product models will, for example, facilitate the automation of activities, increase electronic communication, and push the re-engineering of the design and fabrication processes (Eastman et al. 2002, p.429).

2.1. Definition of BIM

BIM is a complex technology (Kaner et al. 2008, p.303), and it is revolutionizing the building industry (Epstein 2012, p.3). It is a popular buzzword used by software vendors to describe the capabilities that their products offer (Eastman et al. 2011, p.19). According to Succar (2009, p. 357), Taylor & Bernstein (2009, p.69), and Gu & London (2010, p.988), BIM is an emerging technological and procedural shift within all the lifecycle phases of a project in the Architecture, Engineering, Construction and Operations (AECO) industry. BIM makes the construction process easier and faster for everyone involved (Woo 2006, p.1). The concepts and practices of the construction industry are so greatly improved by information technology and business structures that BIM will dramatically reduce the multiple forms of waste and inefficiency in the industry (NIBS 2007, p.1). However, BIM is a relatively new paradigm for the construction industry (Hannon 2007, p.2), and the debate continues about its exact definition and overall scope (NBIMS 2007, pp.23−24).

According to Epstein (2012, pp.4−5) and Kaner et al. (2008, p.305), BIM reflects the change from the use of analog tools to using digital ones. However, Eastman (2009) and Young et al. (2008, p.2) think that BIM is a process and that building a model is just the basis for BIM. Then again, Sacks et al. (2005, p.19) state that BIM is a generic term used to describe a process of generating and managing all the information related to buildings using advanced CAD technologies. The National BIM Standard (NBIMS) defines BIM as "*a digital representation of physical and functional characteristics of a facility*." (NBIMS 2007, p.21). The National Institute of Building Sciences (NIBS) has probably developed the most complete definition of BIM: "*A Building Information Model or BIM utilizes cutting edge open standard digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and it is intended to be a repository of shared information for the facility owner/operator to use and maintain throughout the lifecycle of a facility.*" (NIBS 2006, according to Hannon 2007).

A building information model is a digital, three-dimensional model that is linked to a database of project information (AIA 2007, p.10). Sometimes it is easier to define things through the facts that they are not presenting. Eastman et al. (2011, p.19) have created the following feature list in which they define what kind of a model is not a BIM:

- Model that contains only 3D data and no object attributes is not a BIM model.
- Model that does not support parametric intelligence is not a BIM model.
- Model that is composed of multiple 2D reference files and must be combined to define the building is not a BIM model.
- Model that allows changes to dimensions in one view that are not automatically reflected in other views is not a BIM model.

BIM as an abbreviation can be interpreted in different ways depending on whether it is used to refer to a product, activity or system (NIBS 2007, p.1). When the context refers to a product, BIM means a Building Information Model, when referring to an activity, it means Building Information Modeling, and when referring to a way of working BIM means Building Information Management. Most of the reviewed literature uses the acronym to refer to the activity (Building Information Modeling).

The definition of BIM can be examined further. The letters included in the acronym have their own meanings. Letter B (Building) refers to any man-made built project (Epstein 2012, p.5). These projects include the buildings that we inhabit and use, such as houses, offices and public buildings, but B also includes parts of infrastructure, such as bridges and transmission towers. Letter I (Information) in BIM refers to all the data in the project (Epstein 2012, p.5). Building information models include both geometric and non-geometric data, such as object attributes and specifications (Singh et al. 2011, p.134), and this changes the base of documentation used in the industry from one that is only readable by humans to a new representation that is machine readable (Jeong et al. 2009, p.469). Letter M (Model, Modeling or Management) in BIM refers to the scientific definition of representation (Epstein 2012, p.5). Architects, engineers and detailers creating the models are no longer drawings lines like they were doing a decade ago but creating data that can be viewed by both humans and machines.

2.2. Concept of BIM in the construction industry

BIM is an evolving technology but it is not used consistently in the construction industry (AIA 2007, p.10). However, it is transforming the paradigm of the industry from 2D drawing-based systems to 3D object-based information systems (Jeong et al. 2009, p.469). The 3D objects in the model are not useful without the knowledge used to build it (Ibrahim et al. 2004, pp.610−611) and an intelligent relationship between them (Singh et al. 2011, p.134). When models are completed, they contain precise geometry and data to support the construction, fabrication, and procurement activities through the project (Eastman et al. 2011, p.1).

The BIM concept is built around a single database for each project (Epstein 2012, p.41), and it is a simulation of the real-life project that consists of all the 3D-model components with links to all of the required information (Kymmell 2008, p.28). A BIM database is founded on one or more accurate virtual models (Eastman et al. 2011, p.1) that are seamlessly integrated with a standardized format (Holzer 2008) to digitally construct a building. Open technology platforms are essential to the integration of BIM (AIA 2007, p.10). Tools for BIM are as different from the CAD tools as a slide rule was different from a computer in the past (Eastman 2009; Jeong et al. 2009).

BIM is also a collaborative process (Epstein 2012; NBIMS 2007; Hannon 2007), which means that the different players in the constructions industry must come together (NBIMS 2007, p.21). Hannon (2007, p.2) claims that BIM is as much or more about process and collaboration than about technology. Lee et al. (2006, p.758) think that BIM is a process of generating and managing information in an interoperable and reusable way. To use BIM productively requires exchange of data between disciplines (Eastman et al. 2006), and collaboration is greatly enhanced if the disciplines can share their models not only for viewing but for direct analysis, editing and development (Jeong et al. 2009, p.469). All in all, BIM provides a platform for collaboration throughout the project (AIA 2007, p.10) and the ultimate goal of the concept is to create a complete digital model of the building to generate accurate quantity take offs and cost estimates along with coordinated drawings and details (Ibrahim et al. 2004, p.610).

BIM offers numerous benefits in terms of productivity, such as the ability to rapidly generate design alternatives at different levels and eliminate errors that result from the disparity between different drawings in the current practice (Sacks et al. 2004, p.291). As a first step, BIM could be used to review potential conflicts within the model so that they could be easily discovered and resolved prior to issuing information further in the process (Kaner et al. 2008, p.306). It is time-consuming and complex to make changes to a completed building design using CAD, because this means manually maintaining numerous drawings, but a parametric building information model automates the drawing production and other documentation making the changes feasible and less error-prone (Sacks 2004, p.308). In addition, enhanced cost-estimation accuracy, drastic reduction in engineering lead time, improved customer service, and support for automation in production are some of the productivity and quality benefits of BIM (Kaner et al. 2008, p.305).

2.2.1. BIM as a tool and a process

2D hand-drafting tools and methodologies have been the industry standards for centuries, (Epstein 2012, p.3) and 2D CAD data was typically exchanged between the architectural, engineering, and construction (AEC) parties in the form of a printed set of 2D drawings and documents (Taylor & Bernstein 2009; Singh et al. 2011). According to Eastman et al. (2011, p.17), current 2D paper-centric tools and methodologies include 2D drawings, 3D CAD software, animations, linked databases, and spread-sheets. These 2D CAD tools and methodologies have two strategic limitations: first of all, they require multiple views to depict a 3D object in adequate detail for construction, and secondly, they are stored as lines, arcs and text annotations that are only interpretable by humans and cannot be interpreted by computers (Eastman 2009).

However, as CAD systems have become more intelligent and more users wanted to share data associated with a given design, the focus has shifted from drawings and 3D images to the data itself (Eastman et al. 2011, p.15). BIM techniques are ideal for the storage of data relating to building components or elements within the building together with associated cost and production information (Baldwin et al. 2008, p.340).

Even though 3D models and applications have been used for visualization and design development, the collaboration practices have remained 2D-based (Singh et al. 2011, p.134). BIM moves the construction industry forward from current 2D paper-centric processes towards an integrated and interoperable workflow where tasks are collapsed into a coordinated and collaborative process that maximizes computing capabilities, web communication, and data aggregation into information and knowledge capture (Eastman et al. 2011, p.17).

3D objects in BIM are machine-readable, and this enables automatically checking spatial conflicts in a model (Eastman 2009). This one thing already shows the potential to produce work in the industry more efficiently and in less time (Epstein 2012, p.4). This capability also greatly reduces errors and change orders due to internal errors (Eastman 2009). These direct gains and benefits in operations are one of the primary motivators for the industry to adopt BIM (Becerik-Gerber & Rice 2009). In addition, BIM will beneficially impact all parties in the construction process; designers, engineers, contractors, fabricators and facility operators (Eastman 2009).

Although parametric 3D-modeling systems have existed for structural steel construction for a while, the requirements of the precast industry are quite different (Lee et al. 2006, p.759). Because of this the North American precast industry initiated an information-technology initiative called the Precast Concrete Software Consortium (PCSC) in 2000 (Eastman et al. 2002; Lee et al. 2006; Sacks et al. 2002). The consortium included 15 major precast concrete producers and 17 engineering consultant companies from North America, and it aimed to develop a parametric 3D modeling system that could automate the precast concrete detailing and engineering process (Lee et al. 2006, pp.749−766).

The first step of the PCSC was to undertake careful process modeling of the member companies, to gain understanding of the current workflow, and to identify the opportunities for information technology (Eastman et al. 2002, according to Eastman et al. 2002). They then developed a plan that included specification for design and engineering software of precast concrete building assemblies and individual pieces and for the development of a precast concrete building model (Eastman et al. 2001, according to Eastman et al. 2002). The difficulty with precast concrete piece geometries is that they can differ by project and by company while steel design relies on standard profiles available from multiple plants (Lee et al. 2006, p.759). This parametric application platform has another challenge, too; unlike steel structures, precast concrete elements include nested objects, such as reinforcements, reinforcing strands, and other embeds, which geometrically increase the number of possible combinations of detailing options (Lee et al. 2006, p.759).

The PCSC identified that a library of broadly applicable parametric objects and connections was the only way to provide the desired levels of productivity (Lee et al. 2006, p.759). In addition, the member companies recognized that achieving their objectives, such as reducing engineering lead-time and improving production economies through effective application of the new information systems, will require re-alignment of their business processes and human resources (Sacks et al. 2002, p.52). Companies in the consortium understood that they first needed to re-engineer their business processes in a way that would fully integrate information technology tools to support them. Finally, after a thorough evaluation of 12 software suppliers, the consortium selected Tekla Structures to serve as the base system platform (Lee et al. 2006, p.766).

The primary goal of the PCSC was to reduce costs and duration of precast concrete production through information technology and process re-engineering (Sacks et al. 2002, p.59). According to Sacks (2004, p.308), BIM has two major productivity gains compared to current CAD practices: the first benefit is the direct labor cost of producing drawings and the second is the possibility to automate tasks, such as taking quantities for estimation, structural analysis, and other data-processing related tasks.

According to Eastman (2009) BIM has similar impact on the construction industry as automation had on manufacturing in the 1980s when most manufacturing industries first adopted 3D modeling and digital representations. This indicates that utilizing information systems in the construction industry is an issue of great importance in order to enhance the effectiveness of construction projects throughout their life cycle and across the construction functions (Jung & Joo 2011, p.126).

2.2.2. Implementation of BIM

Replacing a 2D CAD environment with a building-model system involves far more than acquiring software, training, and upgrading hardware (Eastman et al. 2011, pp.27−28). In a 2D CAD design process, building information was typically exchanged between firms in the form of a printed set of plans that also served as the visual representations upon which discussions within and between design and construction organizations were based (Taylor 2007, p.994). According to Epstein (2012, p.51), the primary impact of implementing BIM is the shift in which the work effort will occur in the construction process (see Figure 1.2). Transition from CAD-based technology to object-based CAD technology was an incremental change, while moving to parametric building modeling is a yet bigger change (Autodesk 2007).

However, the significance of BIM implementation for the industry is not a new idea (Gu & London 2010, pp.993−994) but implementation of BIM throughout the building industry is still in its infancy (Epstein 2012, p.4). Design and construction firms are adopting BIM tools slowly when compared to earlier adoption of 2D CAD systems (Whyte et al. 2002, according to Taylor & Bernstein 2009). It is obvious that there was similar resistance to change against the first 2D CAD systems that is now holding back BIM solutions (Autodesk 2007).

Implementation requires some understanding of BIM technology and related processes and a plan for implementation before the conversion can begin (Eastman et al. 2011, pp.27-28). It also requires commitment, planning, testing, and time to develop the best practices and integrate the process, and the transition stays focused by setting goals and by defining a budget and schedule (Epstein 2012, p.22).

According to Coates et al. (2010, p.3), current practices should be first reviewed and analyzed. Based on the findings of Gu & London (2010, p.994), BIM adoption requires changes to four interrelated key domains including work processes, resourcing, scope/project initiation, and tool mapping. In other words, the implementation of BIM will take many steps (Epstein 2012, p.28).

An implementation plan will follow directly from the desired goals and specifications (Kymmell 2008, p.81). There are various levels of BIM adoption, and therefore there is a need for a plan and specific tools to facilitate BIM adoption (Gu & London 2010, p. 988). The implementation plan should describe the deliverables, the process required to produce the desired result, and the resources necessary to accomplish these goals (Kymmell 2008, p.81).

Things rarely turn out as anticipated, but having a detailed implementation plan will help to better respond to the changing circumstances of the process as they present themselves (Kymmell 2008, p.81). After the first BIM pilot project, there should be a noticeable increase in speed and accuracy when the company has matched current methods with standards, and there will be another increase when the company reaches optimum BIM standards (Epstein 2012, p.112). The use of BIM allows efficient development of extremely complex projects in ways that might otherwise not be possible in given constrains of site, time or finance (AIA 2007, p.10).

It is clear that building models can save costs and construction time and support better building performance and control (Eastman 2009). It is also obvious that BIM delivers tremendous business benefits, but gaining them requires departure from traditional ways of working (Autodesk 2007). Although these benefits are clear, integration requires leadership and persistence as well as careful planning (Kaner et al. 2008, p.303). When adopted well, BIM facilitates a more integrated design and construction process that results in better-quality buildings at lower cost and reduced project duration (Eastman et al. 2011, p.1). A growing number of successful project delivery case studies have proven the BIM methodology a truly cost-beneficial and disruptive innovation that is here to stay (Hannon 2007; Eastman 2009).

According to Kaner et al. (2008, p.303), companies have reported that their BIM operators had to undergo a significant change in thinking from a CAD approach to a BIM approach to precast engineering. From a precast concrete construction perspective, the ideal world would be one in which an architect or an engineer and a precast fabricator are able to exchange building information model data between their applications in a seamless fashion (Eastman et al. 2006). However, architectural models are almost never made available to precast companies, and they are experienced by laboriously internally generating the 3D models by interpreting the two-dimensional drawings provided by architects (Sacks et al. 2010, p.420).

It is clear that software tools alone are insufficient for successful BIM adoption (Kaner et al. 2008, p.303). Naturally, since BIM represents a paradigm shift from the use of 2D CAD, the transition is likely to involve personnel issues (Sacks et al. 2005, p.137). Success requires deep changes in terms of work practices, human resources, skills, relationships with clients, and contractual arrangements (Kaner et al. 2008, p.303). It is also likely to present the opportunity for rethinking, and possibly re-engineering, existing workflows and information flows in both design and production (Sacks et al. 2005, p.137).

Progress in adopting BIM is slow but certain (Kaner et al. 2008, p.303). Therefore, companies should prepare strategies and working plans for the adoption phase, and they should implement monitoring procedures to enable benchmarking their progress internally and in comparison with the performance of other companies (Sacks et al. 2005, p.137). Firms should also establish and maintain their organizational knowledge and develop, document and teach the modeling procedures to make progress in implementation (Kaner et al. 2008, p.321).

Figures 2.14 and 2.15 show how the workflow of a precast project designed using BIM differs from one designed using 2D CAD. The main difference is in the changed focus of the modeler. In a BIM workflow, the focus is on the building as a whole and all the work performed on the model while drawings are secondary. In a 2D CAD workflow, all work must be performed on the drawings, and the whole building is only modeled in the designers' minds (Kaner et al. 2008, p.320).

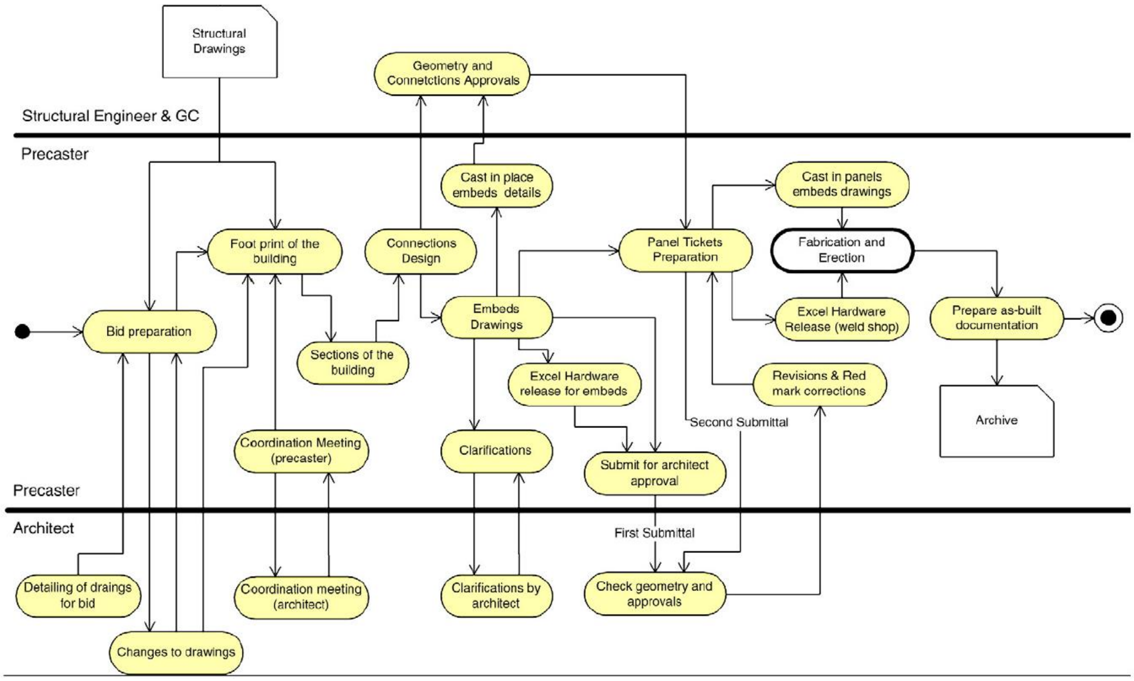

Figure 2.14 2D CAD workflow in precast design (Sacks et al. 2010, p.430).

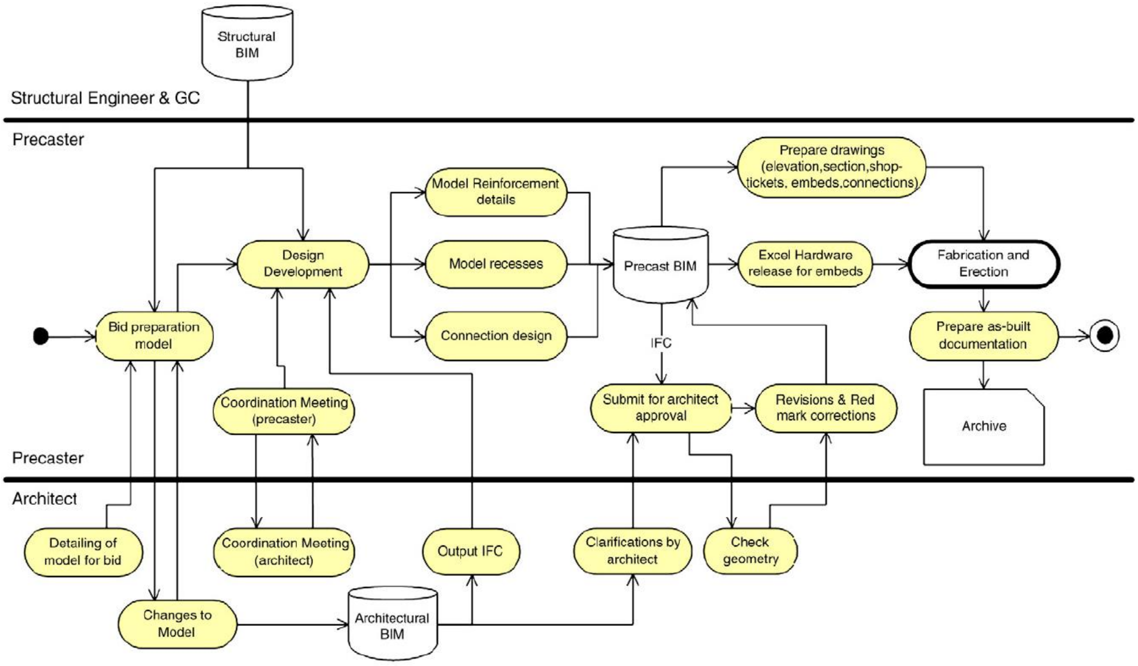

Figure 2.15 BIM workflow in precast design (Sacks et al. 2010, p.431).

Because of this workflow change, some of the companies have decided to pace the adoption in four main stages. The first stage consists of basic 3D modeling. The second stage concentrates on automation of drawing production. The third stage is about preparation and use of sophisticated parametric components, and the final fourth stage focuses on integrated structural-analysis functions. (Kaner et al. 2008, pp.317–321)

Kaner et al. (2008, p.321) claim that the adoption of BIM is challenging but certain in precast companies. The directly measurable benefits of BIM for the precast industry include significantly reduced engineering costs and less costs of rework due to errors (Sacks et al. 2005, p.137). Additionally companies gain clear improvement in engineering design quality, in terms of error-free drawings, and steadily improve labor productivity (Kaner et al. 2008, p.303). Potentially more significant benefits include enhanced cost-estimation accuracy, drastic reduction in engineering lead time, improved customer service, and support for automation in production (Sacks et al. 2005, p.137). However, the most important value of BIM for the precast fabricators is the benefit of shortened lead times for preparing shop drawings (Kaner et al. 2008, p.321).

2.3. Theoretical frameworks for BIM implementation

At least Succar (2009, 2010), Succar et al. (2012, 2013), Coates et al. (2010), Gu & London (2010) and Jung & Joo (2011) have studied the implementation of BIM in the construction industry. All of them have created their own frameworks for BIM implementation, and each of the frameworks reflects various implementation philosophies, and they are inevitably different.

According to Coates et al. (2010, p.1), every adoption of BIM is different by BIM technologies, implementation strategies, and roadmaps, but all of the attempts are motivated by gaining competitive advantage against competitors. The framework created by Coates et al. (2010) is based on one implementation project where the processes of an architects' office were re-engineered to achieve the BIM capability. Coates et al. (2010, p.2) suggest that implementation and adoption should be performed in five stages which are summarized in Table 2.1.

Table 2.1 Five-stage BIM implementation and adoption framework by Coates et al. (2010) (Coates et al. 2010, p.3).

Stage 1: Detail Review and Analysis of Current Practice	Production of Current Process Flowcharts Soft System Analysis Review of IT systems Stakeholder Review and Analysis Identification of competitive advantages from BIM implementation
Stage 2: Identification of Efficiency gains from BIM implementation	Efficiency gains from BIM adoption
Stage 3: Design of new business processes and technology adoption path	Production of detail strategies Documentation of Lean Process and Procedures Identification of Key Performance Indicators
	Documentation of BIM implementation plan
Stage 4: Implementation & roll-out of BIM	Piloting BIM on three different projects (past, current, and future) Training the JMA staff and stakeholders Devising and improving companywide capabilities Documentation and integration of process and procedures
Stage 5: Project review, dissemination and integration into strategy plan	Sustaining new products and processing offerings Evaluation and dissemination of the project

Jung & Joo (2011, pp.127−131) claims that effective BIM implementation can be achieved through comprehensive framework, and it should address all the relevant BIM issues, but at the same time it has to be concise in order to present the key issues in a systematic manner. Figure 2.3 illustrates that the framework consists of three dimensions that are BIM technology, BIM perspective, and construction business functions, and the focus is on practical implementation with six major variables in these dimensions (Jung & Joo 2011, p.127).

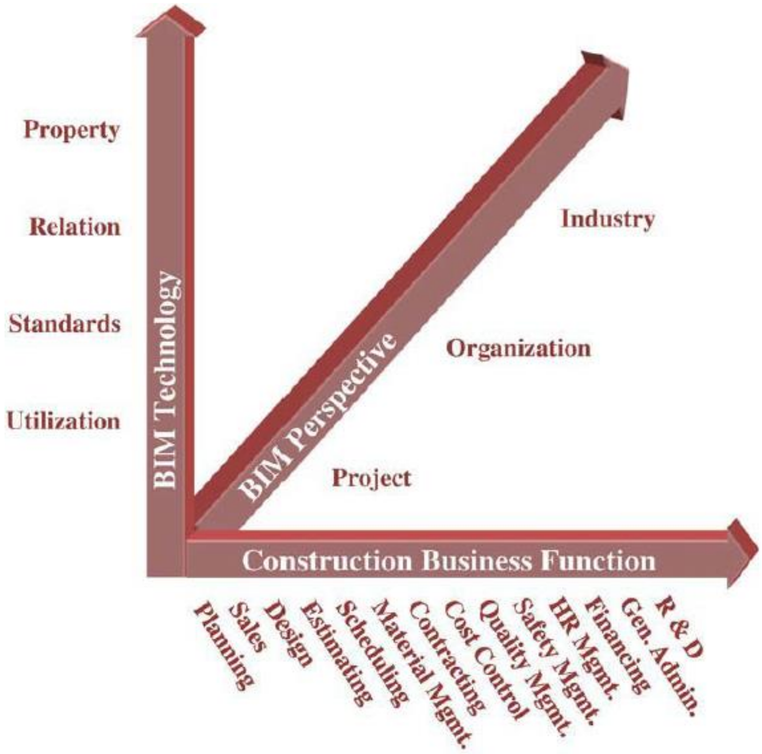

Figure 2.3 Three-dimensional BIM implementation framework (Jung & Joo 2011, p.127).

According to Gu & London (2010), many of the activities in BIM implementation are just common sense, but successful implementation also requires leadership from senior executives and BIM managers. Gu & London (2010) suggest in their framework that BIM implementation consists of four interrelated parts. In the first stage the company has to define and decide the scope, purpose and phases of the implementation, and after that in the second phase, to develop an applied work roadmap. In the third phase, the company has to obtain comprehensive understanding of the BIM software products available, and in the last phase, to train and support the resources. (Gu & London 2010, pp.994–999).

So far, Succar (2009; 2010a; 2010b) and Succar et al. (2012; 2013) have developed the most advanced framework for BIM implementation. Succar (2009; 2010a; 2010b) and Succar et al. (2012; 2013) have explored some of the international guidelines that were publicly available and developed their own BIM implementation framework based on that. The framework identifies BIM Fields, BIM Stages, BIM Steps, BIM Competencies, Project Lifecycle Phases, and a specialized conceptual ontology, and in addition, it introduces the BIM Maturity Matrix, a capability and maturity-assessment and reporting tool. As seen in Figure 2.4, the framework is multi-dimensional and consists of several stages that help companies to approach the implementation from different points of view.

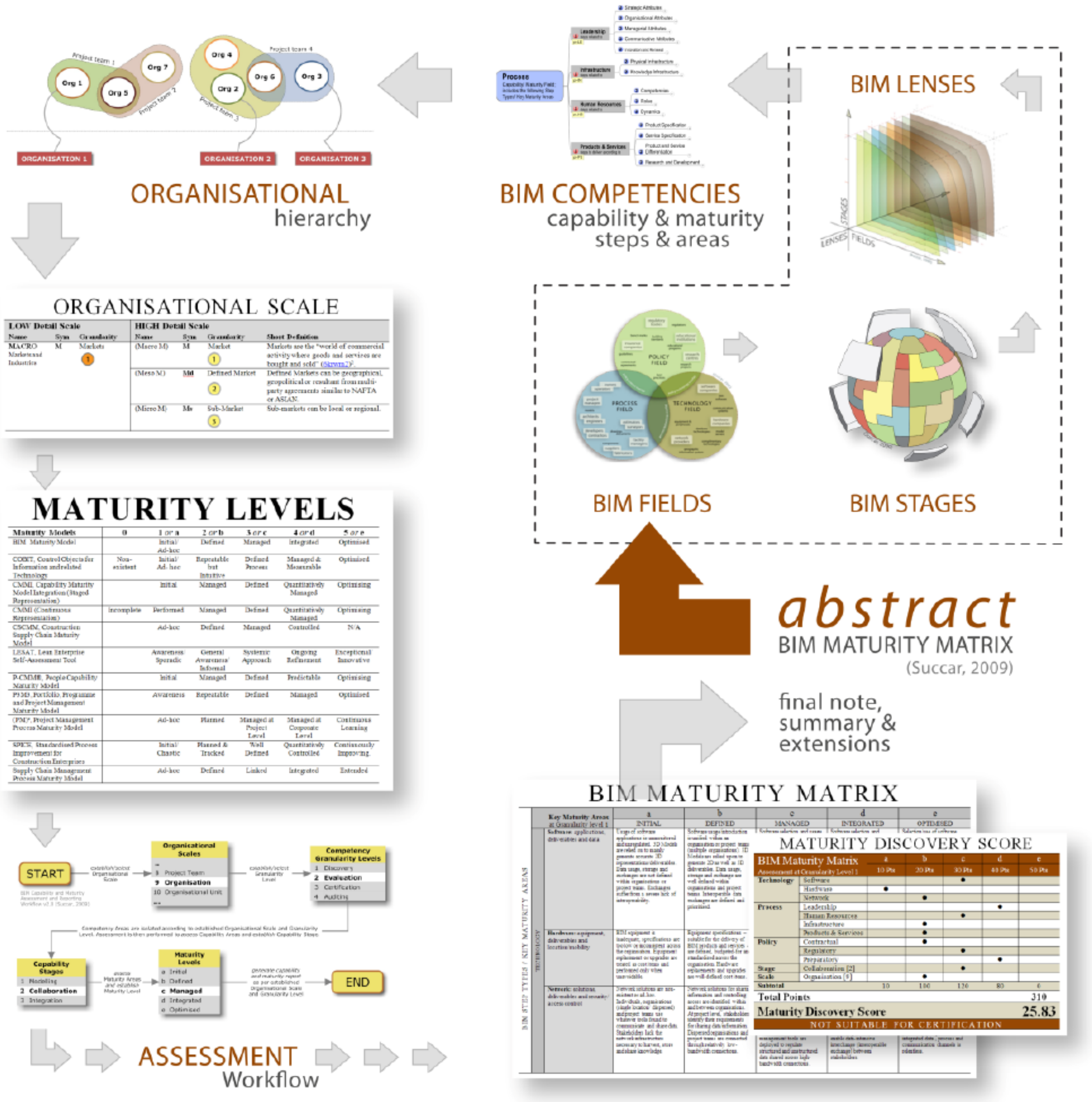

Figure 2.4 Visual abstract of Succar's (2010a) BIM framework (Succar 2010a, p.2).

The BIM framework created by Succar (2009; 2010a; 2010b) and Succar et al. (2012; 2013) is used as a baseline in this study. In this thesis its adequacy for precast fabricators is examined. The framework and its relevant parts will be introduced in detail in the empirical findings chapter.

3. RE-ENGINEERING BUSINESS

The BIM literature review revealed that it is impossible to obtain the full benefits of BIM without having integrated and well-structured processes to support the functions. According to Hammer (1990, p.108), Business Process Re-engineering (BPR) requires looking at the fundamental processes of the business from a cross-functional perspective, which is what BIM also requires. Hammer (1990, p.104) also remarks that the usual methods for boosting performance have not yielded the dramatic improvements that companies need, and heavy investments in information technology have delivered disappointing results because companies tend to use technology to mechanize old ways of doing business, which is quite often the case also in companies that are trying to implement BIM.

Both Peppard & Rowland (1995, p.242) and Hammer (1990, p.112) have stated that re-engineering is not easy and it is full of pain and uncertainty and that companies who have redesigned their internal processes know that success requires a rigorous and structured approach (Hammer 2001, p.89). Re-engineering deals with innovative approaches to business processes rather than incremental improvements to business operations (Belmont & Murray 1993, p.23). These same ideas and issues can be noted among BIM implementation experiences.

According to Peppard & Rowland (1995, pp.45−46), all organizations are built on three main pillars as shown in Figure 3.1: processes, people and technology. When companies start to redesign their processes, these three elements must be aligned to the needs of the market, the customers within the market and to each other (Peppard & Rowland 1995, pp.45−46).

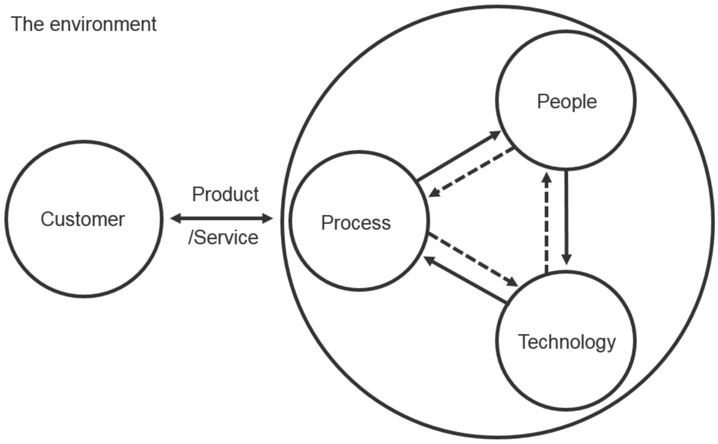

Figure 3.1 Three organizational pillars: processes, people and technology. First the processes must be identified and designed. After that people operate the processes. People are able to perform as well as the process lets them and only to the level of skills,

knowledge and motivation that they have. Technology includes the office and factory technology as well as the infrastructure that supports the processes and people. (Peppard & Rowland 1995, pp.45−46)

Re-engineering as well as BIM trigger many kinds of changes not limited to the business process. Anything associated with the process, such as job descriptions, organizational structures, and management systems, must be reformulated in a more integrated way (Hammer 1990, p.112). Studies by Hall et al. (1994, p.108) revealed how difficult redesigns are to plan and implement and how often they fail to achieve real business-unit impact. In these cases change is probably causing most of the problems, and consultants publicly estimate that as many as 70% of the BPR projects have failed (Bashein & Markus 1994, p.7). Nonetheless, while statics say that re-engineering is often unsuccessful, according to Hammer & Champy (1993, p.221) it is not a high-risk endeavor but some companies achieve dramatic improvements in individual processes only to see overall results decline (Hall et al. 1994, p.107).

According to Hammer (1990, p.107), the heart of re-engineering is the notion of discontinuous thinking, which strives to reach radical levels of improvement. Most of the companies try to use information technology to automate existing processes rather than to redesign new ones (Hammer 1990; Short & Venkatraman 1992; Peppard & Rowland 1995; Hannus 1994; Hammer & Stanton 1999). Therefore it is not surprising that using information technology to redesign internal business processes has been difficult and even failed (Short & Venkatraman 1992, p.7).

Re-engineering is considered to be radical because it challenges the assumptions of status quo, the conventional fragmented and piecemeal process structure, and it requires a process (Hammer 1990; Belmont & Murray 1993). Most of our procedures and processes are no longer valid because they were developed before modern computers and communications existed (Hammer 1990; Davenport & Short 1990; Belmont & Murray 1993). According to Peppard & Rowland (1995, p.35), companies should rather concentrate on defining how the work should be done and then consider how technology might help with this, but most companies are just looking for efficiency savings through automating existing tasks.

Companies need to break away from the old rules: how we organize and conduct business (Hammer 1990, pp.104−105), and their managers need to break loose from outmoded business processes and create new ones (Hammer 1990, p.108). If the plans are sufficiently broad, all the old support systems become obsolete (Hall et al. 1994, p.113). Transformed business processes enable companies to operate faster and efficiently and to use information technology more productively (Hammer & Stanton 1999, p.1). According to Peppard & Rowland (1995, pp.203−204), key to success is to turn the conservativeness and resistance into active involvement in organizations.

3.1. Definition of re-engineering

The common elements used to describe re-engineering are: rapid and radical redesign, dramatic improvement of existing business processes, cross organizational process integration, and new way of thinking (Belmont & Murray 1993; Klein 1994; Hannus 1994; Hammer & Champy 1993). According to Peppard & Rowland (1995, p.20), re-engineering is an improvement philosophy, and Hammer & Champy (1993, p.34) say that it simply means starting over.

All in all there are three main improvement programs: incremental improvement (process improvement), radical improvement (process innovation), and combination of these two (see Figure 3.2). Initiatives for process improvement are often continuous in frequency, ongoing goal and simultaneous improvements across multiple processes, whereas process innovation initiatives start with a relatively clean state, and they have a discrete goal (Davenport 1993, p.11). Re-engineering can be defined as Process Innovation.

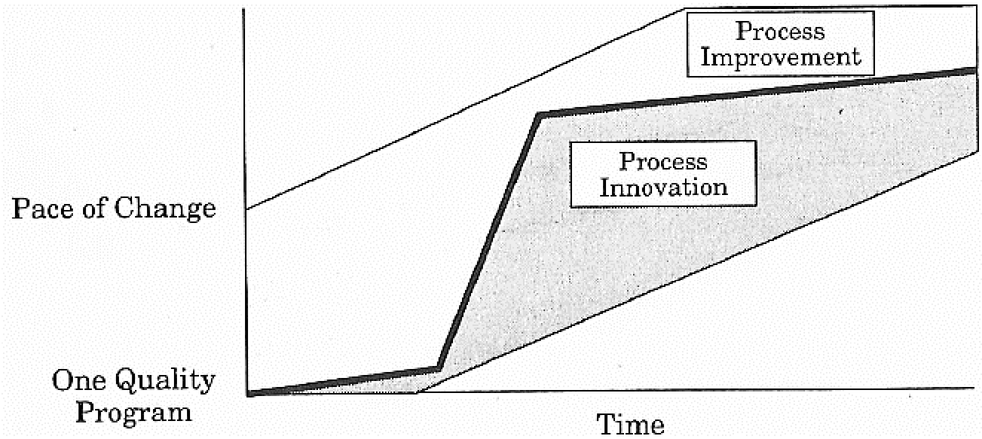

Figure 3.2 Example from combining process improvement and process innovation: first a company attempts to stabilize a process and begin continuous improvement, then it strives for process innovation (Davenport 1993, pp.14−15).

According to Hannus (1994, p.222), the starting point of re-engineering is the redesign of business processes with the help of modern information technology and communication technology, and the objective is to achieve radical process improvements through these actions. After all, re-engineering aims to achieve performance improvements both on individual process level and the whole organization level by redesigning the processes, which maximizes their value-added content and minimizes everything else (Peppard & Rowland 1995, p. 20).

3.2. Re-engineering process

Hammer (1990), Davenport & Short (1990), Davidson (1993), Davenport (1993), Klein (1994), Hinterhuber (1995) and Peppard & Rowland (1995) have studied re-engineering and proposed how re-engineering should be implemented in companies. Hammer (1990), who published the first re-engineering article in Harvard Business Review in the summer of 1990 introduced seven basic principles of re-engineering, and his followers then developed the process further. According to Hammer (1990, pp.108−112), the seven principles of re-engineering are: 1) organize around outcomes, not tasks; 2) have those who use the output of the process perform the process; 3) subsume information-processing work into the real work that produces the information; 4) treat geographically dispersed resources as though they were centralized; 5) link parallel activities instead of integrating their results; 6) put the decision point where the work is performed, and 7) build control into the process and capture information once and at the source.

Davenport & Short (1990) introduced a phased re-engineering process, and this process includes five major steps (see Figure 3.3). Their description is sufficiently general so that it can be applied to most types of organizations and processes.

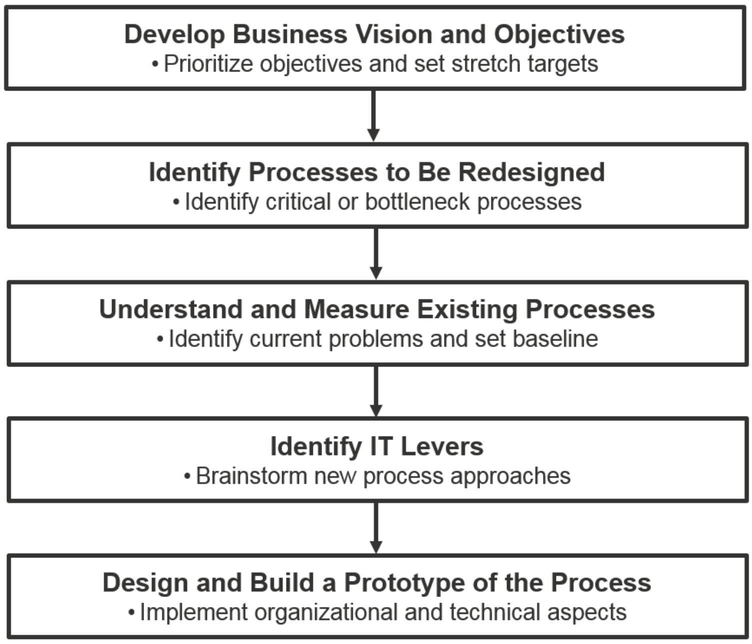

Figure 3.3 Five steps of process redesign: develop the business vision and process objectives, identify the processes to be redesigned, understand and measure the existing process, identify IT levels, and design and prototype the new process. (Davenport & Short 1990, p.13).

According to Davenport & Short (1990), companies should first internally undertake specific business vision and objectives and identify redesigned processes as well measure existing processes. Davenport & Short (1990) suggest these five phases because of two reasons: firstly companies need to understand what their problems are so that they do not repeat them, and secondly these measurements must serve as a baseline for the future improvements. After companies have measured their existing processes, they can start to build new ones, first by identifying the opportunities of information technology and after that implementing the redesigned processes to organizations. (Davenport & Short 1990, pp.13−16)

Davidson (1993) has identified three phases of business transformation (see Figure 3.4). According to Davidson (1993), in the first phase companies can achieve excellence by automating their internal operations. In the second phase companies can achieve value-added processes and services through enhancement of customer and supplier interfaces. And finally in the last phase, companies can achieve totally new core competencies through redefinition and by creating new business units. (Davidson 1993, p.66)

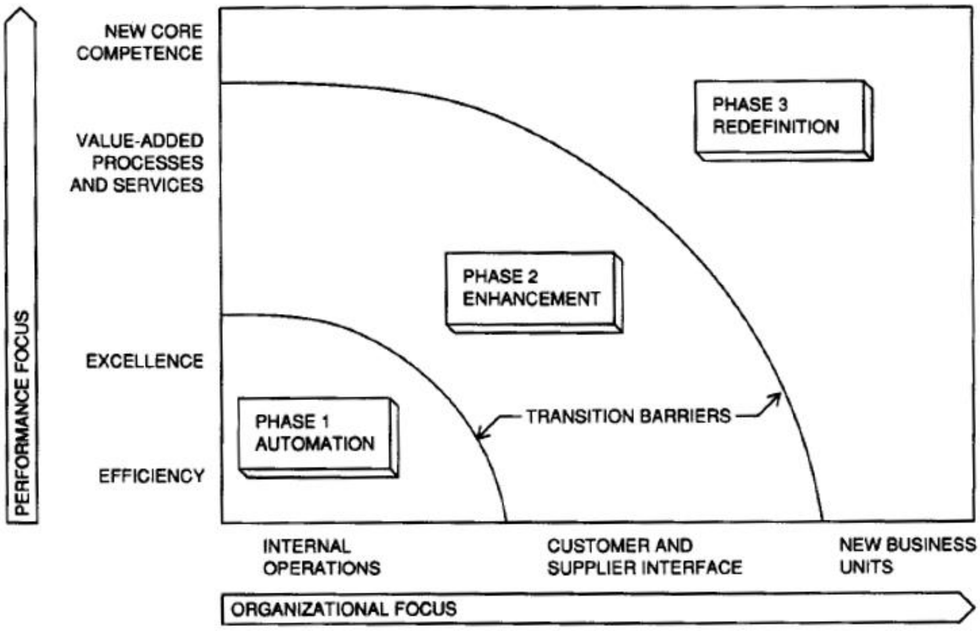

Figure 3.4 The three phases of business transformation: automation, enhancement and redefinition (Davidson 1993, p.66).

Klein (1994) has developed a methodology that consists of five stages: Preparation, Identification, Vision, Solution and Transformation. According to Klein (1994), in the first stages companies should select both people, who perform the project, and processes that are to be re-engineered, as well as develop ideal customer-oriented business-model process. After that Klein (1994) suggests that companies should define the technical requirements and create a detailed implementation plan. In the final transformation phase, companies just need to implement their re-engineering plans. (Klein 1994, pp.25−26)

Hannus (1994) suggests that companies should first question and redesign their whole value chain before implementing any new information technology capabilities (see Figure

3.5). This kind of a way of working leads to more light and agile information technology solutions rather than implementing on top of existing processes. (Hannus 1994, pp.227–228)

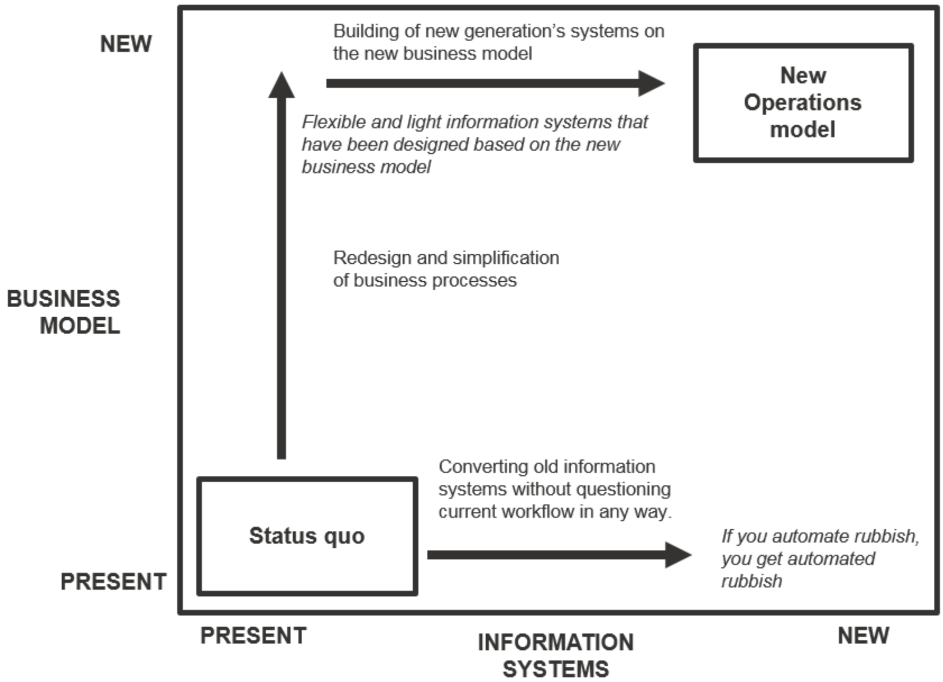

Figure 3.5 Principle of re-engineering as a starting point for information technology development. When companies are not following this process, they adapt beneficial technology in a wrong way that does not bring the desired result. (Translated by Antti Soikkeli from Hannus 1994, p.227)

Peppard & Rowland (1995) have outlined an overall approach to a re-engineering program (see Figure 3.6). According to Peppard & Rowland (1995), this kind of framework is necessary so that companies are more likely to achieve success. (Peppard & Rowland 1995, p.204)

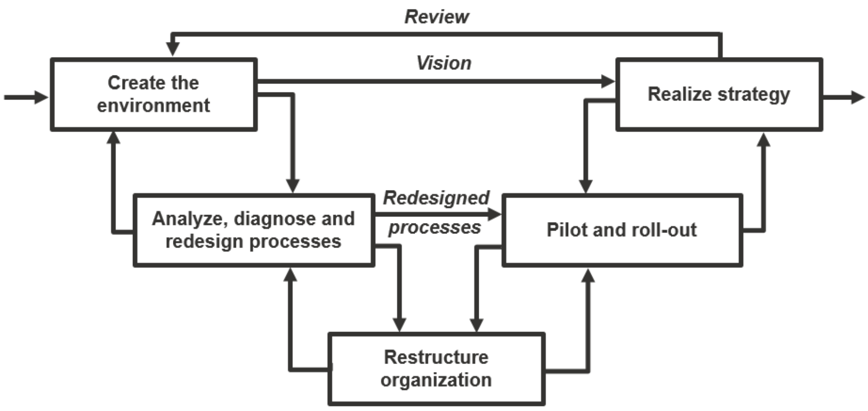

Figure 3.6 An overall approach to re-engineering (Peppard & Rowland 1995, p.204).

Hinterhuber (1995) has divided his re-engineering implementation process into six steps. These steps include the basic guidelines for re-engineering implementation. Hinterhuber's (1995) implementation steps are: defining the business process, installing a process owner, measuring and mastering the business processes, coordinating the business process in question with other business processes, concentrating on critical business processes, and continuous improvement. (Hinterhuber 1995, p.68)

The most comprehensive framework for a re-engineering process has been developed by Davenport (1993). Davenport (1993) has identified five high-level steps that are quite similar to the ones of Davenport & Short and lead companies through process innovation (see Figure 3.7). (Davenport 1993, p.25)

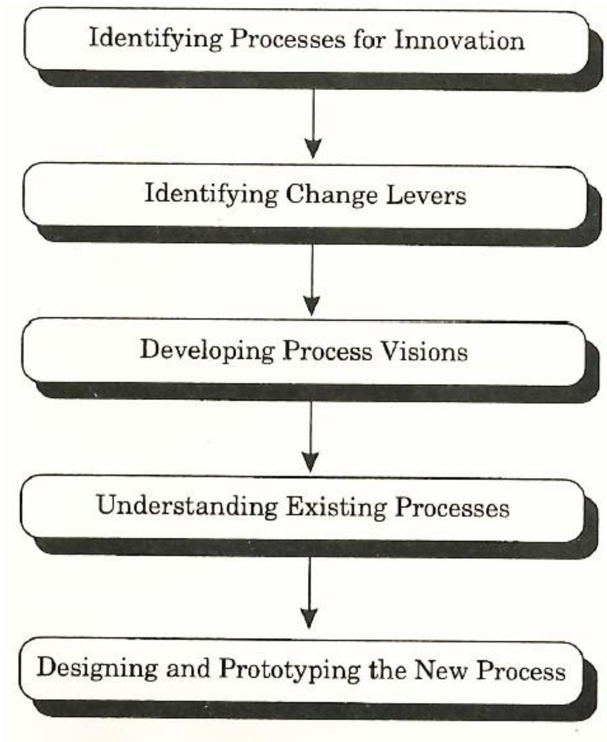

Figure 3.7 A high-level five-step approach to process innovation: identifying processes for innovation, identifying change levers, developing process visions, understanding existing processes, and designing and prototyping the new process (Davenport 1993, p.25).

Based on the review of different re-engineering theories presented above, some conclusions can be made regarding the BIM implementation process. It seems that all of the theories, at least on some level, suggest that existing processes and ways of working should be evaluated and documented before starting to execute the actual re-engineering project. Another thing that clearly emerges from the theories is the phased approach to change. In other words, above theories suggest that re-engineering efforts should be divided into more manageable phases that are easier to manage, execute and measure.

3.3. Role of IT in re-engineering

Academics like Davenport & Short (1990) and Hammer & Champy (1993) state that re-engineering and IT are natural partners and that IT plays a crucial role in the process but it can be easily miscast by companies. According to Belmonte & Murray (1993, p.26), business processes cannot be restructured without IT, and Hannus (1994, p.109) claims that IT has several different roles in the re-engineering process depending on the level of change.

According to Hammer & Champy (1993, p.89) and Davenport & Short (1990, p.12), the fundamental error that most companies make when they look at technology is to view it through the lens of existing processes when it should be exploited through the latest capabilities of technology to achieve entirely new goals. Hannus (1994, p.109) divides the roles of IT in three categories: facilitating role, enabling role, and driving role. Traditionally the role of IT has been a facilitating one, but IT also carries an enabling role in radical improvement of core processes, and a driving role of IT can lead to totally new products, services and ways of working in the whole industry (Hannus 1994, pp.109−114).

Davenport & Short (1990) see that the role of IT should be considered already in the early stages of redesign. This is useful, because IT capabilities definitely impact the organization. Davenport & Short (1990) have identified eight different impacts of IT capabilities (see Table 3.2). (Davenport & Short 1990, p.16)

Table 3.2 Eight IT capabilities and their organizational impacts: transactional, geographical, automation, analytical, informational, sequential, knowledge management, tracking, and disintermediation (Davenport & Short 1990, p.16).

Capability	Organizational Impact / Benefit
Transaction	IT can transform unstructured processes into routinized transactions
Geographical	IT can transfer information with rapidity and ease across large distances, making processes independent of geography
Automational	IT can replace or reduce human labor in a process
Analytical	IT can bring complex analytical methods to bear on a process
Informational	IT can bring vast amounts of detailed information into a process
Sequential	IT can enable changes in the sequence of tasks in a process, often allowing multiple tasks to be worked on simultaneously
Knowledge Management	IT allows the capture and dissemination of knowledge and expertise to improve the process
Tracking	IT allows the detailed tracking of task status, inputs, and outputs
Disintermediation	IT can be used to connect two parties within a process that would otherwise communicate through an intermediary (internal or external)

3.4. Different levels of re-engineering

Venkatraman (1994) and Hannus (1994) have extensively studied the levels of re-engineering, and both of them have published their own frameworks for it. Venkatraman (1994, p.74) proposes a five-level hierarchy framework for business re-engineering. Figure 3.13 is a schematic presentation of the framework that also describes the levels of transformation and the different ways to approach the transformation. The first two levels of the framework can be seen as evolutionary steps and three later ones as revolutionary steps. Organizations can approach business re-engineering from two different perspectives: the lower left arrow "*Seek Efficiency*" focuses on fixing current weaknesses, and the upper right arrow "*Enhance Capabilities*" aims to create strategic capabilities for future competition. (Venkatraman 1994, pp.74−85)

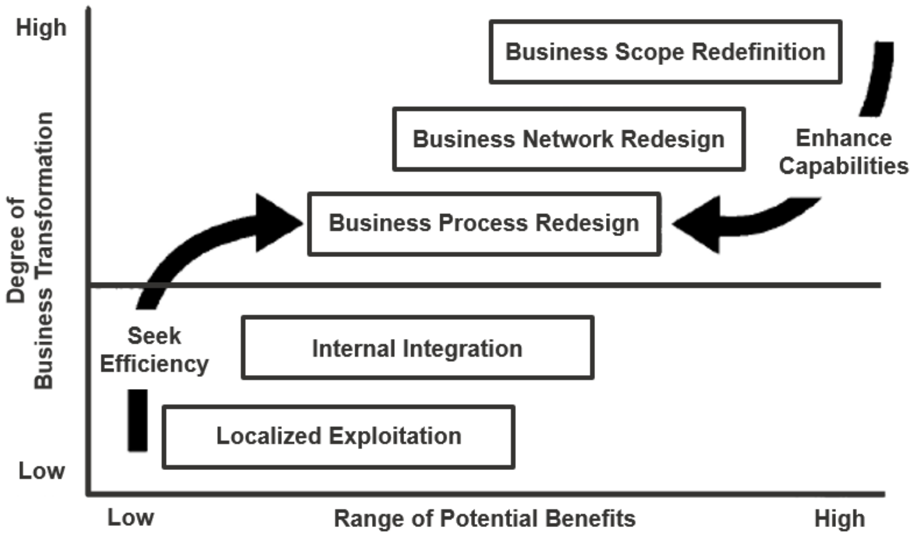

Figure 3.13 Five levels and two ways to approach business re-engineering (Venkatraman 1994, p.85).

Venkatraman (1994) suggests that the first thing that companies should do is to identify and decide the level of transformation where the benefits are in line with the potential costs and the efforts that are needed for organizational changes. On the first level of the framework companies implement standard IT applications with minimal changes to the business processes to respond to some operational problems or challenges. The second level of the framework reflects a more systematic attempt to implement IT capabilities throughout the entire business process. This level involves both technical interconnectivity and business-process interdependence, because neither of these are sufficient alone. The third level of the framework represents a situation where the benefits of IT implementation are not fully realized if IT is superimposed on the current business processes, and that is why a careful analysis of the current situation is needed before starting the redesign. On the fourth level of the framework, multiple participants in a business network redesign and implement IT capabilities to enhance the network. The fifth level of the framework shows what role IT plays in influencing business scope and the logic of business relationships within the extended business network. (Venkatraman 1994, pp.74–83)

Hannus (1994, p.231) has constructed his framework (see Figure 3.14) based on Venkatraman's (1994) framework (see Figure 3.13). The main difference between these two frameworks is that Hannus (1994) has added one level to his framework and divided his framework into four main categories that include all in all six steps. However, Hannus (1994) has not taken into account the different approach perspectives that Venkatraman (1994) includes in his framework.

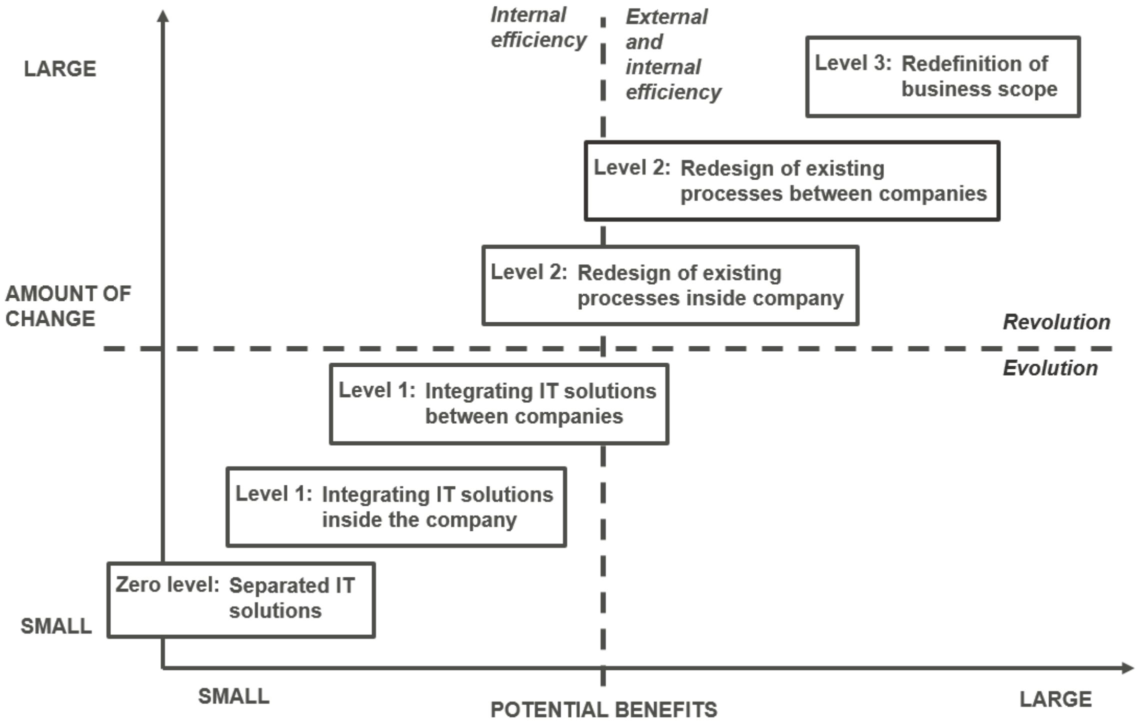

Figure 3.14 The different levels of technology-driven business re-engineering (Translated from Hannus 1994, p.231).

The first level of the framework (Zero Level) describes the situation where IT solutions separated for certain purposes are developed for an organization's internal purposes. The second level (Level 1) consists of two steps: integrating IT solutions inside the company and integrating IT solutions in a business network. On these two levels, companies do not question their existing business structure and processes. The starting point of the third level (Level 2) is the redesign of existing core processes and structures. This can be done either internally or in collaboration with other companies. The last level (Level 3) reflects the change of a company’s business idea and essential expansion of its business scope based on new IT capabilities. (Hannus 1994, pp.231−232)

3.5. Re-engineering framework in BIM implementation

According to Eastman et al. (2002, p.429), product models facilitate the automation of activities and electronic communication as well as the re-engineering of engineering processes. Other academics and industry experts like Sacks et al. (2002), Sacks (2004), Sacks et al. (2004), NBIMS (2007), and Jung & Joo (2011) have discovered that there is a relation between BIM and re-engineering, but so far none have really studied the relation of these two paradigms. Jung & Joo (2011, p.131) note that strategic advantages and managerial benefits attained from BIM in terms of re-engineering need to be quantified and clarified.

Based on the findings of the first literature review, the author of this study decided to carry out another literature review regarding BPR. During the second literature review, the similarity and opportunity of these two paradigms, BIM and BPR, became clear to the author. Figure 3.15 visualizes author's deduction on the relation of BIM and BPR.

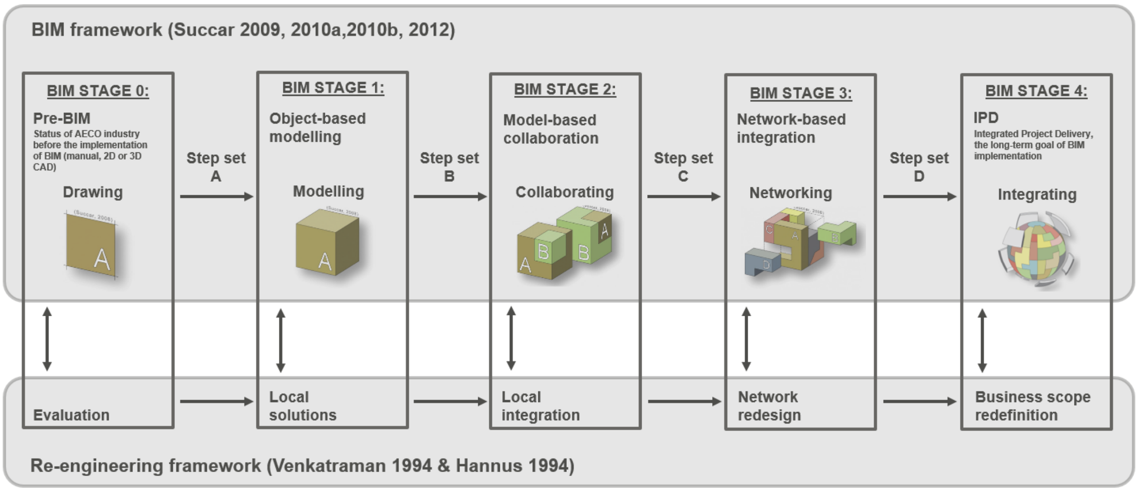

Figure 3.15 Visualization of author's deduction on the relation between BIM and BPR.

After the first literature review it was obvious that BIM is a process tool that enables more straightforward processes in the construction industry as well as in the structural precast concrete industry. For example, the results of a study by Sacks et al. (2004, p.206) highlight the aspect of precast management processes that may be re-engineered through appropriate application of information technology. Another fact that emerged during the first literature review was that BIM implementation is mainly about change and how to manage it correctly inside the organization as well as with the chosen external partners. Re-engineering is one paradigm that might help to better manage the change that is needed in the company.

The amount of change during the implementation depends on the depth of the implementation in the company's operations as well as in the network surrounding it. According to NBIMS (2007, p.19), successful re-engineering must be coordinated at a facility lifecycle-level rather than sub-optimized within current industry and software-vertical divisions, because the major benefits of BIM are communication and the value of the information created by the BIM process itself.

NBIMS (2007, p.28) pinpoints that a minimum goal for the re-engineering work processes (during the implementation of BIM) is to define a minimum BIM for specific purposes. This definition refers to zero-level BIM implementation (see Figure 3.15). However, NBIMS (2007, p.42) states that in the future, highly integrated data exchange will support new opportunities for re-engineering. This definition refers to the BIM Stages three and four in the BIM framework (see Figure 3.15). Currently, this is the reality, since data exchange between software has been improved and different formats have taken a huge leap forward over the last couple of years.

Sacks et al. (2004) did an exercise with 23 North American structural precast concrete fabricators the purpose of which was to map existing work processes as well as BIM-enabled future ways of working. According to Sacks et al. (2004), this exercise enabled companies to examine their practices in fine detail, and in many cases this has already led to re-engineering of their current work processes. One of the findings of the study was that reducing interfaces and complexity is a key component in re-engineering the process to reduce important design lead time. (Sacks et al. 2004, p.214)

According to Sacks et al. (2004, p.206), it is clear that BIM offers significant improvements for the structural precast concrete industry in the competition against other structural frame alternatives, but so far its implementation has been the bottleneck that has hindered the results, and this has also triggered the industry to realize all the benefits available with BIM. The author of this study sees that the way in which re-engineering divides and manages the change that is occurring offers a considerable opportunity that needs to be further examined.

4. RESEARCH APPROACH

This chapter outlines the research setting in which the study was conducted and provides an overview on the structural precast concrete industry and the case companies. The chapter is concluded with a description of selected research methodology.

4.1. Research setting

This study was carried out for a Finnish software company that drives the evolution of digital information models to provide greater competitive advantage for companies operating in the construction industry. This software company was established in the mid-sixties, and it has customers in over 100 countries and offices in over 20 countries as well as a global network of resellers.

The BIM software that the company develops was originally created based on the needs of the steel industry, and it has been used by the industry since the early nineties. Today, the product is the market leader and most advanced BIM software used by the steel industry. The company has been developing a BIM solution for structural precast concrete industry since 2003 on top of the same BIM technology platform.

The company's BIM solution for the precast industry has been on the market for about ten years. Since the launch of the solution, there have been clear indicators that the implementation of a BIM solution into the processes of the structural precast concrete industry is far more challenging than, for example, into the processes of the structural steel industry. This is not only a challenge for one software vendor but it seems to concern all vendors offering BIM solutions especially for the structural precast concrete industry.

Only a handful of academics and industry experts have tried to find a solution for this challenge, but so far no study has been able to find or offer any concrete solutions for this problem. This was one of the initial reasons why this thesis was started and why it is needed. The aim of this thesis is to create a BIM implementation process and a guideline for the structural precast concrete industry that any company could follow when starting BIM implementation efforts, regardless of their current status with BIM and technology adoption. For practical reasons, it would be good if the process could be cut into smaller manageable pieces that would be easier for companies to follow. Different kinds of steps, step types, competencies, and progress levels need to be defined so that it is possible to follow up on the progress of implementation. Based on the experience of the author, it is also crucial that the current processes are first evaluated and the desired future target is determined and that information-gap analyses of the current state and future target is done based on this as the first step of implementation.

4.2. Structural precast concrete industry

Buildings are complex products that contain a relatively large number of distinct parts that are made of different materials and collected in multiple assemblies for different design, analysis and production purposes (Sacks et al. 2004a, p.291). Conventional on-site construction methods that are used in concrete buildings have for long been criticized for lengthy construction times, low productivity, poor safety records, and large quantities of waste (Chen et al. 2010, p.665). Construction projects vary in terms of type, complexity, scale, location, and contract type, all of which influence the design and production of the precast concrete elements (Sacks 2004, p.303). Basically all construction projects pass through three major life cycle phases: the design phase, the construction phase, and the operations phase (see Figure 4.1) (Succar 2009, p.363).

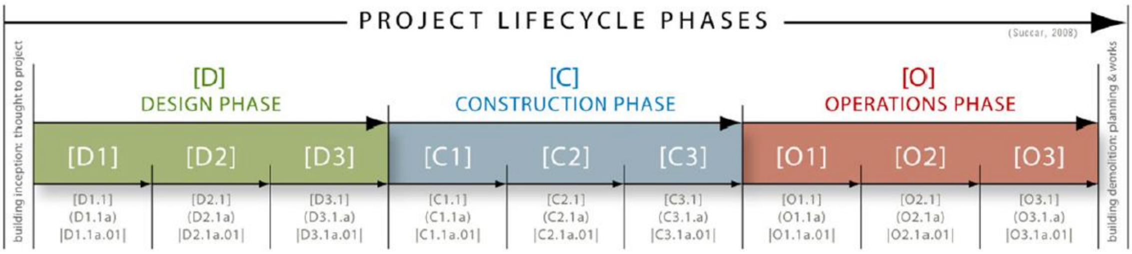

Figure 4.1 Visual, linear model of life cycle phases of a construction project. Phases are further subdivided into multiple sub-phases, activities, sub-activities and tasks (Succar 2009, p.363).

The structural systems of buildings can be divided into three major providers by the material used: the steel industry, the cast-in-place concrete industry, and the precast concrete industry. These three industries are quite different from each other. The steel industry typically involves separate organizations for design, fabrication and erection, except in some cases where a steel fabricator has undertaken the whole design and build of a structure as a service. The cast-in-place concrete industry is even further fragmented, often with separate mix-suppliers, formwork providers, and reinforcing-bar and concrete placement specialties. In contrast, the precast concrete industry sometimes has its own batch facility, does its own engineering design and fabrication, and often does its own erection. The precast concrete industry appears to be the most integrated of these three industries, allowing it to gain efficiencies through re-engineering that are not available to its competitors.

At the moment all standards, codes and reference materials in the precast concrete industry are organized around 2D drawings and associated formatting conventions (Eastman et al. 2002, p.2). Automation is common within most activities, but communication between them is mostly dependent on paper drawings and reports (Sacks et al. 2002, p.58). Careful design and coordination during building design is required for the prefabricated pieces to fit correctly when erected (Eastman et al. 2002, p.3).

Precast concrete is a fairly young construction method in the construction industry (Eastman et al. 2002, p.3), in which concrete is cast in molds and cured in a controlled environment, then transported to the construction site and lifted and fixed in the structure (Kaner et al. 2008, p.304). Precast concrete requires additional consideration in aspects such as lifting, storage, transport and installation (Baldwin et al. 2008, p.339).

Precast concrete factories can only serve limited geographic regions, restricted by the maximum distance over which their products can be transported economically (Sacks et al. 2004b, p.207). This means that many precast concrete fabricators operate more than one plant and they have relative uniformity in the basic section profiles. There are no standards for element dimensions; this means that each fabricator or each factory produces, for example, double-tee elements with various basic dimensions (Sacks et al. 2004b; Eastman et al. 2003). Precast concrete provides building components with a high level of design flexibility, significantly improved quality control over on-site construction, fast erection, and reduced costs, and it is a significant contributor in many building types including commercial and institutional buildings and parking garages (Eastman et al. 2003, p.248).

According to Eastman et al. (2003, p.248), precast concrete is recognized worldwide to offer significant potential advantages as a construction method, but decisions to employ precast concrete are still largely based on familiarity and personal preferences rather than rigorous data (Chen et al. 2010, p.665). Many factors influence the market share of precast concrete, but most, such as labor costs, climate, and the relative costs of alternative construction types, are beyond the control of precast producers (Sacks et al. 2004b, p.206). The North American precast concrete industry only holds a small share of the building construction market, and it consumes 7.9% of the concrete produced in the United States, but in contrast to that, much larger market percentages are held by European and especially Scandinavian precast industries. For example in Finland, 70% of the concrete produced is used for precast concrete (Eastman et al. 2003; Sacks et al. 2004b).

According to Kaner et al. (2008, p.304), there are five main actors that participate in the precast construction process: owner, architect, structural engineer, precast fabricator and erection crew. Precast concrete elements consist of several parts such as embeds, reinforcement, pre-stressing, connection hardware, etc. that are cast into them, and these are essentially same for all companies in the industry (Sacks et al. 2002, p.58). In most countries, the precast concrete fabricator is responsible for the detailed engineering design of its product, and some of the fabricators maintain engineering staff in house, but most of the fabricators procure the service from independent engineering design firms (Kaner et al. 2008, p.304). All in all, precast concrete engineering and production are relatively uniform from the point of view of physical products, but they are relatively diverse in the range of business and management procedures that characterize the companies involved, and their communication is heavily dependent on paper documents, which means that processes contain many interfaces both within each company as well as externally (Sacks et al. 2002, p.61).

Andresen et al. (2000, p.58) have found out that research and development are typically underfunded in the construction industry, and according to Brummet & Olsen (2002, p.69), the precast concrete industry is no exception. Brummet & Olsen (2002, p.69) claim that the average total investment in research and development reported by the precast concrete fabricators for 2001 amounted to only 0.03% of net sales and that the maximum investment for any individual company was 0.2%. According to Sacks (2004, p.302), some of the reasons for low investment figures originate from complicated information-technology impact assessment, which is the result of vertical fragmentation in the industry and the fact that construction projects are collaborative efforts involving numerous different companies in ad-hoc groupings that typically do not persist beyond the life of a single project.

Sacks et al. (2003, p.54) claim that the fabricators who want to fully realize the benefits of parametric 3D modeling must develop the building model in an integrated parametric way, modeling has to be comprehensive, and models need to cover as much of the project scope as possible and also drive the production of all drawings and reports. Some fabricators have already integrated their production with Material Resource Planning (MRP) or Enterprise Resource Planning (ERP) solutions (Eastman et al. 2003, p.249). Sacks (2004, p.303) notes that customization, training, testing, and implementation of the necessary organizational and human-resource changes typically develop over a number of years, which means that the new 3D technology is not on the fast track to achieve savings and efficiency.

Because of the fragmentation of the industry, information-technology adoption and investment decisions must ultimately be taken at the level of an individual company. The set-up of precast fabricators is not homogeneous: some of the fabricators outsource the engineering and detailing activities while others do all in house, and some mix both methods. Some fabricators employ their own erection teams while others do not. All in all, the majority of precast concrete fabricators roughly divide their activities to four stages: engineering and detailing, production, storage, and erection. (Sacks 2004, p.303)

In most cases, precast concrete fabricator's process initiates with a contract bid, then moves on to cost-estimating, bidding, contract award, assembly layout design, structural analysis, detailed piece design, production, handling, shipping, erection, scheduling, and project control (Sacks et al. 2004b, p.209). Sacks et al. (2002, p.58) have analyzed three general observations about precast concrete fabricators: (1) fabricators have significant diversity in the management processes; (2) there is little variation in the types and characteristics of the basis precast pieces produced by the fabricators across the industry; and (3) the fabrication process includes a significant number of interfaces as information is passed from department to department within companies.

Relating to the first observation point Sacks et al. (2002, p.58) have stated that the sequence of activities, such as project acquisition, detailed design, cost-estimating, quality control, and scheduling, vary from company to company, and some of the diversities are due to differences in building type, contract type, company policies, and existing management information systems. Internal and external review procedures add additional interfaces to the third observation point, and while automation is common within most activities, communication between them is mostly dependent on paper drawings and reports (Sacks et al. 2002, p.58).

While high-level process phases, their sequence, and the basic precast concrete product types are relatively uniform across all companies, significant differences are apparent at a detailed level (Sacks et al. 2004b, p.214). According to Sacks et al. (2004b, p.214), the reason for this is the fact that companies specialize in either design-build, subcontracting, or component supply, and these differences in contractual arrangements show direct correlation with the types of buildings produced.

Sacks et al. (2004b, p.214) list some of the main differences in the lower levels of the process between the precast concrete fabricators: the degree of details that the companies invest in design for cost-estimation before contract closure, approach to mold design, which depends on building and product types that the fabricator has, and the performance of engineering design, which is done either in house or outsourced to engineering consultants. According to Sacks et al. (2004b, p.214), engineering lead-time from award of contract until the beginning of fabrication takes currently a minimum of six to eight weeks. Based on this generic top-level process model, Sacks et al. (2004b, p.206) recognized that significant improvements in the competitiveness of the precast industry might be achieved through integration and automation of their information-dependent processes.

4.3. Interview questions and case company overviews

The main purpose of the interviews was to obtain empirical data and experiences from the project participants regarding the whole implementation process. In this thesis, the author has divided the structural precast concrete fabricators into three categories according to size: small companies having one to three factories and operating in one state or country, mid-sized companies having four or more factories and operating in several states or countries, and big corporations that have several factories in many countries and operate possibly on more than one continent. This trisection was done only for this thesis by the author, and it bases on the author's experience of different precast fabricators and how these have approached their earlier BIM implementation efforts. One representative company was chosen from each of these three categories, and the interviews required a person who had hands-on experience of implementation processes.

A set of questions was prepared for the interviews, and the same set was used in all of the interviews (see Appendix 1). The questions were grouped into three different categories, the purpose of which was to obtain information of what happened before, during and after BIM implementation. The first set of questions aimed to obtain information about previous information technology or software implementation experiences that the company possibly had as well as about the expectations for upcoming implementation and the reasons to choose a particular solution for the company. The purpose of the second set of questions was to obtain information on what had happened or should have happened during the actual implementation. The third set of questions aimed at obtaining information on how to improve the implementation process, what had been learned from the process, and whether the solution was used as had been thought at the beginning.

Face-to-face interviews were held during 2012, and all interviews lasted nearly two hours. The interviews were open-ended and held in a conversational manner. The author used the same set of questions for all interviewees, and this was used as a baseline for the interviews. After all of the interviews had been conducted, the author transcribed the interviews from the recorder and reviewed the transcripts.

4.3.1. Case 1: small local company

The first interview was conducted in Baden-Württemberg, a state in the southern part of Germany. The case company is a small precast concrete fabricator that has two factories pretty close to each other in the state of Baden-Württemberg. This small-sized company is specialized in the production of detached private houses the frame structure of which is made of precast concrete elements. The company also fabricates structural precast concrete elements for the frames of industrial, commercial and public buildings.

Typical elements for the company to fabricate for industrial projects include various types of beams, columns, walls, and slabs, and for the detached-house projects they only produce wall and slab elements. The company has its own internal design and detailing office where they implemented BIM software. The elements were fabricated manually with the help of drawings, but the company had just made an investment to a new automated production line which will need model data in the future. New fully automatized production line was still under construction during the interview.

Two employees of the case company participated in the interview, and they were interviewed simultaneously. Both of the interviewees were heavily involved in the new software implementation process. One interviewee was a senior designer who was head of the design department and whose responsibility during the implementation was to coordinate the project. The other interviewee was a junior designer, one of the designers in the design team and also the main user of the software. His role during the implementation was to execute actual implementation in the company and the related hands-on tasks.

4.3.2. Case 2: mid-sized regional company

The second one of the three interviews was conducted in the software supplier's premises in Finland. The mid-sized precast concrete fabricator company based in Germany has six factories scattered in different parts of the country. This case company fabricates precast concrete elements to both building and infrastructure projects. For building projects, they fabricate various types of beam, column, slab, wall and stair elements, and for infrastructure projects, which include bridges, tunnels, noise barriers and wind power stations; they fabricate various types of girders, slabs and project special elements.

The company has its own internal design and detailing office where they implemented the BIM software. In addition, the case company also uses external subcontractors to engineer, design and detail the precast concrete elements for their projects. While implementing BIM software, the case company also expected their subcontractors to switch from current design software to the same BIM software. This company had more sophisticated technology in use in their fabrication process than the first case company, but the processes of their six factories also involve manual tasks. The second case company had also just invested in a new fully automated production line which was under construction during the interview.

As the interview took place in the software supplier's premises, only one person from the case company was interviewed. This interviewee was working in the corporate development department, and he was responsible for the company’s model-based processes. He was responsible for the implementation of different software solutions in particular, including BIM, and for ensuring communication between different software solutions. His role during the implementation was to create a plan for the implementation, supervise the progress of the implementation, and make sure that the BIM software was properly linked to the company's other information technology solutions.

4.3.3. Case 3: large global corporation

The last of the three interviews was also conducted in the software supplier's premises in Finland. This large global precast corporation is based in France, and it has over 100 factories and sales offices in 20 countries. The corporation has operations in practically every country in Europe, and added to this, it also has facilities in the northern part of Africa as well as in Southeast Asia. The case company fabricates all types of precast concrete elements to both building and infrastructure projects.

As the company has several factories in several countries, their way of working is somehow different compared to the first two companies that were interviewed. The corporation basically involves three kinds of companies from a design point of view: those with their own internal engineering, design and detailing departments including precast concrete design, those without their own internal engineering, design and detailing department that outsource design to subcontractors, and those that are a mix of the first two, which means that they perform some of the engineering, design and detailing tasks in house and subcontract some of the tasks.

The implementation process for this kind of a large corporation was different from the previous two companies interviewed. Each of the companies inside the corporation were individually responsible for the implementation of BIM software. However, the employees of each company responsible for the implementation formed a group that occasionally gathered and shared their knowledge regarding the best practices as well as future visions.

One person responsible for BIM implementation in Finland was interviewed from the third case company. He was working in the corporate development department located in Finland, and his role was to ensure that the implementation of BIM software proceeded as planned.

4.4. Research methodology

Usually when a new researcher is starting research work, it is not easy to exactly define how to proceed, especially when the area of research is new, the problem is difficult to structure, and availability of data is unsure. The only way to start in these kinds of situations is to create a rough plan on how to proceed and then define the plan in more detail as research moves forward. Another piece of advice is that in these kinds of new research areas, a literature review, concept analyses, or exploratory analyses are good ways to examine large volumes of research data on the topic, and usually after this first step it becomes clearer how to continue the research and which research strategy and method to use. (Olkkonen 1994, p.82)

In the beginning it was not at all clear how to start the thesis or how to proceed, but based on Olkkonen's (1994) suggestions, a rough research plan was created, and the first step was to conduct a comprehensive literature review on the theory related to the topic. The literature review, which was the first step of the thesis, was conducted in the form of exploratory research. After the literature review, the way to move forward became clear, and the research strategy as well as the methods were decided for the rest of the research.

Action-analytic research method was chosen as the first research method for this study. The reasons behind the selection were clear, since according to Olkkonen (1994, p.82), the action-analytic research method is suitable for new research-problem areas where the problem is hard to structure and the researcher has to start with a rough plan and define the method on-the-go as the work progresses. It is typical for the action-analytic research method to start with a literature review, as was done with this study, and usually after the review it becomes more clear how to continue the research and which research strategy methods to choose for the rest of the work (Olkkonen 1994, p.82). Figure 5.2 describes the structure of action-analytical research method, and Figure 5.3 summarizes the general description of the principle behind the action-analytic research method (Olkkonen 1994, pp.74–75).

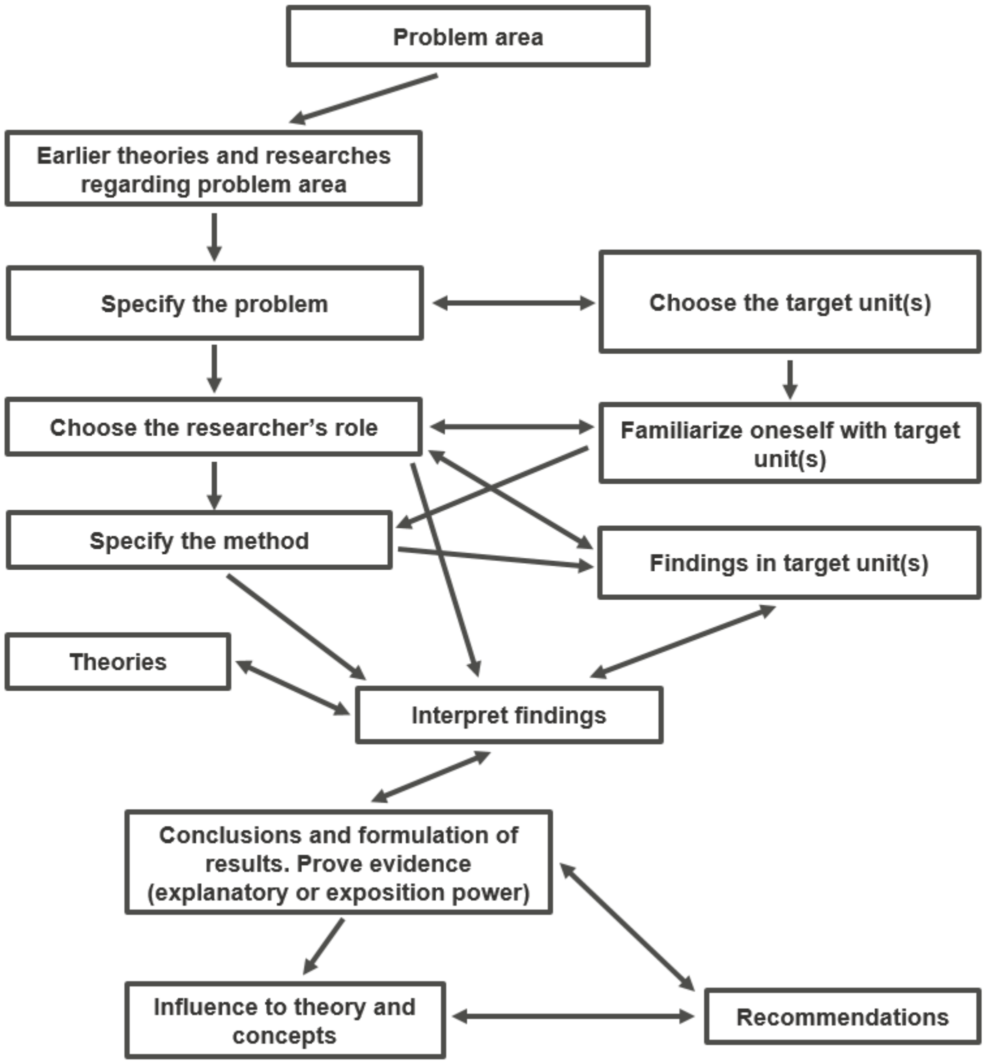

Figure 5.2 Structure of action-analytic research method (Translated from Olkkonen 1994, p.72).

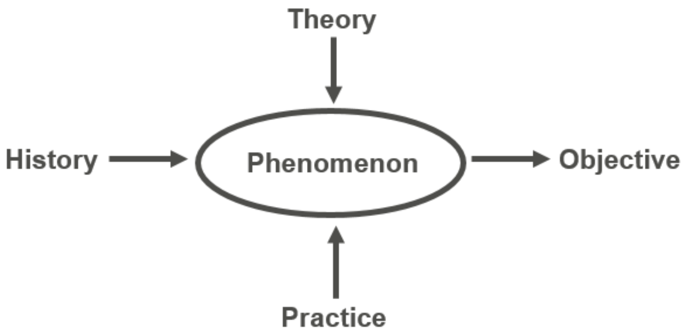

Figure 5.3 Description of a principle that focuses on the studied actions behind the action-analytic research method. It emphasizes the target-oriented approach of the research as well as examination of actions as a development process. (Translated from Olkkonen 1994, p.75)

This study focuses on a phenomenon that is a complex change process mainly planned, managed and executed by the people in the organizations. The research work was concluded tightly connected to the author's understanding of the phenomenon. Data was interpreted by the author in a way that he himself understood the phenomenon.

4.4.1. Conducting two literature reviews

Olkkonen (1994, p.82) suggests that action-analytic research should be started with either a review or analyses to obtain deeper understanding of the phenomenon. This thesis was started with a literature review regarding the use of product models in the construction industry. The aim of the literature review was to obtain better understanding of the phenomenon and how it has been studied by academics and industry experts. The purpose was also to find and develop the concepts of the phenomenon, which would then help in shaping and managing the chosen problem area.

Since the first steps of the literature review it became evident that the doctrine of the phenomenon was very limited and quite recent, and as the literature review proceeded, it became quite soon clear that the focus should only be on BIM, which is the most researched product-model theory by academics and industry specialists. After this conclusion the literature review was first used to find data about BIM studies and how BIM has been used in the construction industry. The second aim was to obtain same kind of data but especially related to the structural precast concrete industry.

The results of the literature review were clear, and the continuation of the research work was evident as anticipated in Olkkonen (1994). As a result of the literature review, the author decided that a second literature review was needed for a totally different theory and that a set of case interviews were needed from different types of structural precast concrete fabricator companies. As a next step, the second literature review was started on BRP theory and the case companies were selected followed by preparation and execution of the interviews.

The topic of the second literature review was re-engineering that was chosen as a comparable theory because based on the first literature review, it was evident that the companies implementing product models in construction were facing similar problems as the companies implementing ERP systems during the nineties. The second literature review was quite different to conduct compared to the first one because most of the related research data was collected in the nineties and there were only very little recent research data available. Furthermore, re-engineering was going through some kind of *hype* in the beginning of the nineties, which probably happened due to academics like Hammer (1990) and Davenport (1993) placing great weight on it and the new generation of computers and internet providing opportunities that did not exist before. This led to the doctrine becoming massive that forming a completely different situation compared to the first literature review. The first thing to do was to figure out the principles behind re-engineering, and after that it became evident that the research work needed to focus on the various change theories based on re-engineering. As the literature review proceeded, it became obvious that the cases handling ERP implementations either done by academics or industry specialists were really good sources of data. After the second literature review was finalized, it became clear how the theory of re-engineering complemented the theory of BIM that had been studied at an earlier phase.

Information search for both of the literature reviews was done at Aalto University's Otaniemi Campus Library. *Alli* collection catalogue was used to obtain information from printed materials that exist in all of the Aalto University's libraries. In addition, *Nelli* e-resource was used to obtain information from latest articles and journals. Search words such as BIM, Virtual Building, and Product Modeling were used in the first literature review to find the right kind of information sources. Later on, precast was added as a search word to find precast-focused BIM literature. Search words such as BPR, re-engineering, and ERP implementation were used in the second literature review to obtain the right type of sources regarding re-engineering.

4.4.2. Types of case-study designs

According to Yin (2003, p.39), there are four basic types of case study designs based on a 2x2 matrix (see Figure 5.4). The matrix shows that every type of design will include the desire to analyze contextual conditions in relation to the case, and the dotted lines between these two indicate that the boundaries between them are not likely to be sharp. The matrix also shows that single- and multiple-case studies reflect different design situations and that within these two variants, there can be a unitary unit or multiple units of analysis. (Yin 2003, p.39)

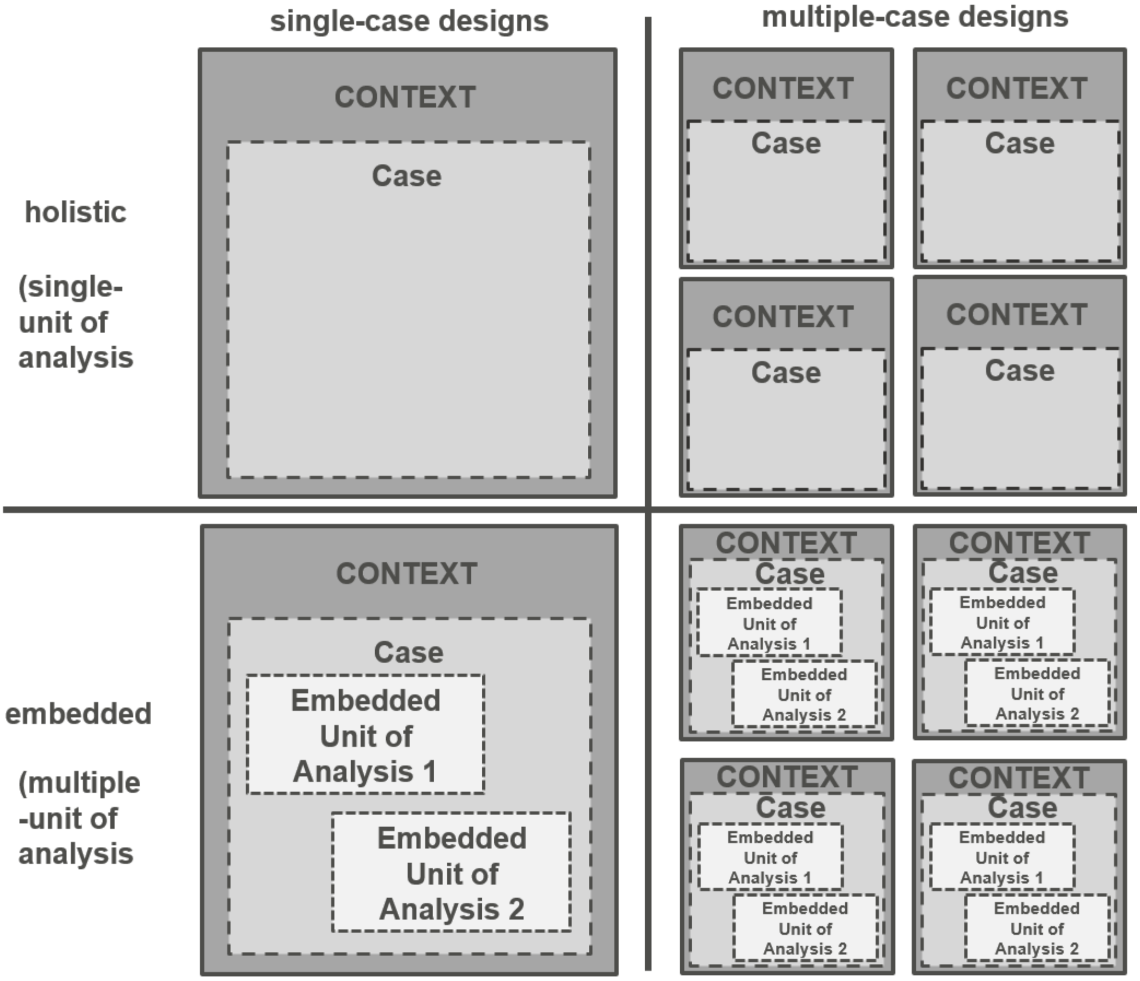

Figure 5.4 Basic types of designs for case studies: single-case (holistic) designs (Type 1), single-case (embedded) designs (Type 2), multiple-case (holistic) designs (Type 3), and multiple-case (embedded) designs (Type 4) (Yin 2003, p.40).

After the first literature review, it was obvious that several cases were needed from different types of structural precast concrete fabricators. It was decided that the cases should be done using the holistic multiple-case design because the context of the studied phenomenon as well as the conditions in which the phenomenon was taking place in the chosen companies were not the same. According to Yin (2003, p.47) and Olkkonen (1994, pp.106−107), with multiple-case design, every case should serve a specific purpose within the overall scope of research and each case should be typical and as representative as possible from that specific group, and the number of cases should be determined so that it is possible to prove the evidence of the research method.

In the replication approach, each individual case study consists of a whole study, but then both individual cases and multiple-case results should become the focus of a summary report, and furthermore, the report should indicate how and why a particular proposition was demonstrated for each individual case (Yin 2003, p.50). This thesis uses the replication approach because each of the interviews was handled as its own individual case study, but in the end of the research, all of the findings from the three individual cases where summarized. In the beginning, three different case types where chosen, because according to the author's prediction, there might be contrast or at least some discrimination between the case companies.

5. EMPIRICAL FINDINGS

This chapter presents the results of the research work conducted. It first presents and summarizes the findings of the case company interviews and then introduces suggestions for the implementation process. Next, the BIM implementation framework for precast fabricators is introduced accompanied by more detailed steps and levels of the implementation process and guideline. Finally, the end of the chapter presents the tools to follow up and analyze the progress of BIM implementation.

5.1. Case company interview results

The findings of the interviews are presented based on the same logic as the interview: first the reasons, expectations and experiences are being discussed, second the events during the implementation are being discussed, and third the learned lessons from the implementation process are being discussed. In the final chapter, the findings are summarized and the received suggestions for the implementation process are introduced. Replication approach is being used when showing the case company interview results.

5.1.1. Before implementation findings

Regardless of the size and the type of product offering of the company, all interviewees said that the main reason to adapt BIM was the need of data that they were not able to obtain from their previous systems. Two of the companies had just invested in new production machinery that needed the BIM data for the manufacturing of the precast elements. The company that was not investing in machinery needed the data to run their production more efficiently through linking the BIM data to their ERP system and on-site actions.

Expectations for the implementation varied between companies. The smallest company expected the new BIM tool to just replace their old design system with a new one and thus deliver the necessary production data faster, easier and more accurately. The mid-sized company expected to move from 2D to 3D and at the same time optimize their production. In the biggest company, there was a gap between higher and lower-level expectations. On a higher level, BIM implementation was expected to penetrate the whole design process in all of the company's locations. In reality, the implementation was executed in small, more manageable phases.

All of the interviewed companies had experiences from previous software implementation projects, but for some of them, implementation had taken place more than 20 years ago. All companies had previous experience from CAD software implementation as well as from either ERP or Management Information System (MIS) software implementation. In addition, the mid-sized company had experience from project management software implementation, and overall it seemed that this was the most advanced company from a software implementation point of view.

5.1.2. During the implementation findings

All companies seemed to possess some kind of a plan for the implementation, but the quality of the plans seemed to vary, and the contents and schedules were quite different. Although they had a plan, they said that the schedule should have been faster since especially for the two smaller companies the implementation process turned out much longer than originally planned. The two bigger companies were satisfied with the support that they received from the software provider during the implementation process, and they also felt that their questions and problems were handled in an acceptable time. The smallest company was not that satisfied with the support and question-handling, but its experience improved considerably after changes in training personnel.

According to all interviewees, communication during the implementation was good, and especially the two bigger companies were satisfied with the level of communication. However, the smallest company felt that in the beginning there was communication yet many misunderstandings. A deeper discussion revealed that this experience was due to one person at the software vendor who was then replaced with another trainer, which immediately improved their experience of communication.

Experiences from installation and trainings varied a great deal. The smallest company did not have any problems with the standard installation and basic trainings, but when they moved to more advanced trainings, problems started to emerge. The mid-sized company experienced a totally opposite order, since they had some problems in the beginning with both installation and trainings but the experience improved when the implementation proceeded further. The biggest company did not have any problems with either installation or trainings, but they mentioned that to find suitable persons for the trainings was the most challenging issue in this phase.

The biggest challenge during the implementation for all of the companies was to change the mindset of users from a 2D CAD system to a 3D BIM system. The main reason for this was the fact that the design process itself differs greatly between the systems. In addition, the two bigger companies mentioned that to reach the desired efficiency in the output creation they needed much more work than was anticipated. The smallest company noted that difference in the expectations between management and the design office caused some challenges, which also caused additional stress in the design office.

5.1.3. After the implementation findings

All three companies said to be using BIM as planned, but they all also said that certain minor goals had not been achieved yet. The smallest company reported not to have met the requirements originally set for the software but to have met the new updated requirements that were set after they faced some problems during implementation. The mid-sized company only missed efficiency in the usage of the software, and the biggest company was satisfied with usage in basic frame-creation but experienced some problems with complicated external wall elements.

All three companies indicated different key learning points in the process. The biggest company said that in the beginning of implementation they quickly learned the importance of key users, and they also learned that a cautious approach was a good choice. The mid-sized company learned that good communication is key to success, but they also reported that software implementation always turned out more difficult than expected. The smallest company said to have understood the importance of internal training of the users after the basic installation is finalized.

All of the companies have a plan on how to expand BIM usage to their processes. On a general level, all of the companies were satisfied with the software, but there were some minor details that they would like to see improved. All of the companies also agreed to recommend and choose this particular software as the most advanced BIM software available on the market for the precast industry.

5.1.4. Lessons learned and suggestions for implementation

The case companies were given a chance to present their suggestions for the BIM implementation process as well as to share their learned lessons in the end of the interviews. The comments received mostly addressed practical issues but some involved higher-level views.

According to the case companies, one of the key aspects of BIM implementation is that the full support of top management to the people executing it in the organization. Since the implementation is not a small exercise, there is a need to have Project Managers on both the precast fabricator and the software vendor side. There is also a need for regular meetings especially in the beginning of the project.

It was suggested that companies first need to train two to four main users, depending on the size of the company, who implement the software to the company's processes. A minimum of two persons need to be trained so that they can reflect on the problems faced. It was also noted that these main users should be taken out of the daily business to let them focus on the new software and to also provide them enough time to set up the system. The main users should receive basic as well as advanced training first, after which they are able to execute the company set-up with the help of the software vendor.

After the main users have successfully performed the company set-up, more users can be trained. These regular users who use the software for modeling, detailing and creating the output for production and not for set-up development should receive basic training from the software vendor and after that more advanced training from the company's main users with the company set-up. An old completed project would serve as a good training project because the software users could then focus only on the software and the new design process in contrast to the design of the structure itself. An old project would also provide a nice benchmark on how efficient the new way of working is compared to the old way of working.

When a company decides to "*go live*" with the new software, the easiest way to start is to use the software to create the bidding models, as in this case they only need to create the model and not to concentrate on the details yet. It was noted that some companies have started live projects with full detailing successfully, but it would be better to first take it easy and make sure that everything is working well. As the final comment, the companies emphasized the importance of keeping to the new system despite facing some difficulties in the process, since returning to the old system to solve problems easily creates a regressive pattern where users of BIM software always return to the old CAD system when they face problems with the new software

5.2. BIM implementation process

This chapter introduces a BIM implementation process for structural precast fabricators. The findings from both literature reviews were used to create this process, and Succar's (2009, 2010a, 2010b) BIM implementation framework as well as Venkatraman (1994) and Hannus's (1994) levels of re-engineering were used as a baseline when the process was constructed. Figure 5.1 illustrates Succar's general implementation framework for BIM. Succar's framework is divided into five phases: status quo, which usually involves 2D CAD and drawing-based processes (pre-BIM), three fixed steps (object-based modeling, model-based collaboration and network-based integration), and variable ending point that enables unforeseen future advancements (Integrated Project Delivery, IPD) (Succar 2009; Succar 2010a).

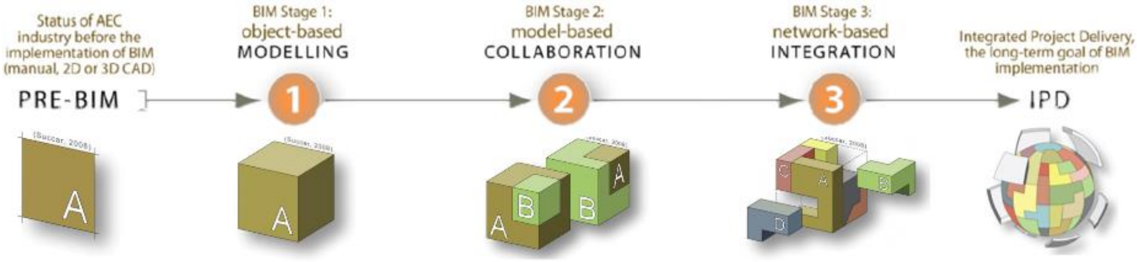

Figure 5.1 Linear visualization of Succar's BIM implementation framework stages (Succar 2009; Succar 2010a).

Succar (2009, pp.362–363) proposes that companies implement BIM gradually and consecutively as a series of stages to reach the desired BIM maturity level. The five stages in the BIM implementation process that Succar (2009, 2010a; 2010b) determines in his framework match the different levels of re-engineering that Venkatraman (1994) and Hannus (1994) have determined in their studies (see Figure 3.15). According to Venkatraman (1994, p.74–85), the first two steps of the framework can be seen as evolutionary steps and the three later ones as revolutionary steps. This matches Succar's implementation framework, since the two first stages are based on existing processes and the last three stages require some re-engineering of existing ways of working. Venkatraman (1994, p.74–85) notes that companies can approach re-engineering from two different perspectives: using a bottom-up method "*Seek Efficiency*" (see Figure 3.13), which focuses on fixing current weaknesses, or using a top-down method "*Enhance Capabilities*" (see Figure 3.13), which aims to create strategic capabilities for the future.

5.2.1. Evaluation phase

According to Succar (2009, p.364), five years ago most of the companies in the construction industry were in Pre-BIM stage, which is also the starting point of Succar's BIM implementation framework. But based on the latest BIM market reports made by Bernstein et al. (2010), Jones & Bernstein (2012, 2014a, 2014b), Lee et al. (2012), and Young et al. (2008, 2009), many more companies in the construction industry have started to implement BIM in their processes, and at the same time most of the companies are trying to achieve the benefits only by trying to fit the new technology in their existing processes. In practice this means two things: quite a few companies have achieved the revolutionary benefits and savings that BIM can offer, and most of the companies are still working with the centuries-old drawing-based process, which in Succar's framework means that most of the companies in the construction industry are still either in a Pre-BIM or object-based modeling stage.

Above findings on the current status of the construction industry support the idea of evaluation before actual implementation, where status quo and future target are being evaluated. In addition, according to Davenport (1993, p.139), improvement as well innovation initiatives require a great deal of detailed information on current processes. Successful implementation of BIM consists of several things, but probably the most important single factor during the implementation is how well the change that happens when a company’s drawing-based processes and ways of working are being transformed to the BIM way of working is being managed. When companies evaluate status quo and future targets they should also at the same time consider at least the following four issues related to change: (1) the ways to execute the change, (2) the capability to implement the change, (3) the level of challenge for the organization, and (4) the ways to prepare for the change.

Davenport (1993, p.158) suggests the following options for the first issue: a phased introduction, pilot, new business unit, or full cut-over. The first option is in line with the basic idea in Succar's BIM implementation framework, and also a pilot and a new business unit are somehow possible for the structural precast fabricators, but a full cut-over would be somehow difficult or even impossible especially if the new process involves customers, revenues, or valued employees as Davenport (1993, p.158) puts it.

The different levels of BIM just like re-engineering require different levels of change from an organization. According to Hannus (1994, p.116), an organization’s willingness to implement change and innovations is influenced hugely by its former success and performance (see Figure 5.2). Analyses of the past provide an answer to the second question. Hannus (1994, p.116) claims that if a company is in a crisis, it is not hard to justify the change. Successful companies also see the change as a possibility to move forward, but companies that are performing well or weakly do not see the benefit of change, which then makes the change process more challenging (Hannus 1994, p,116).

Figure 5.2 Company’s willingness to change in different situations (Translated from Hannus 1994, p.116).

According to Hannus (1994, pp.264−265), there are two factors involved in change: scale and ambition level that needs be taken into account when estimating the impact of change in an organization (see Figure 5.3). The scale of change defines how deeply the change will influence the company's processes. The different levels are sub-processes, core processes, and value chain. The ambition level defines how change will influence the company's current way of doing business in the industry, and its levels consist of continuous improvement (streamlining), radical redesign (process innovation), and redefinition of business scope (business innovation). When these two components are put together, it is possible to estimate how challenging the change will be for the organization, which was the third question that was set above.

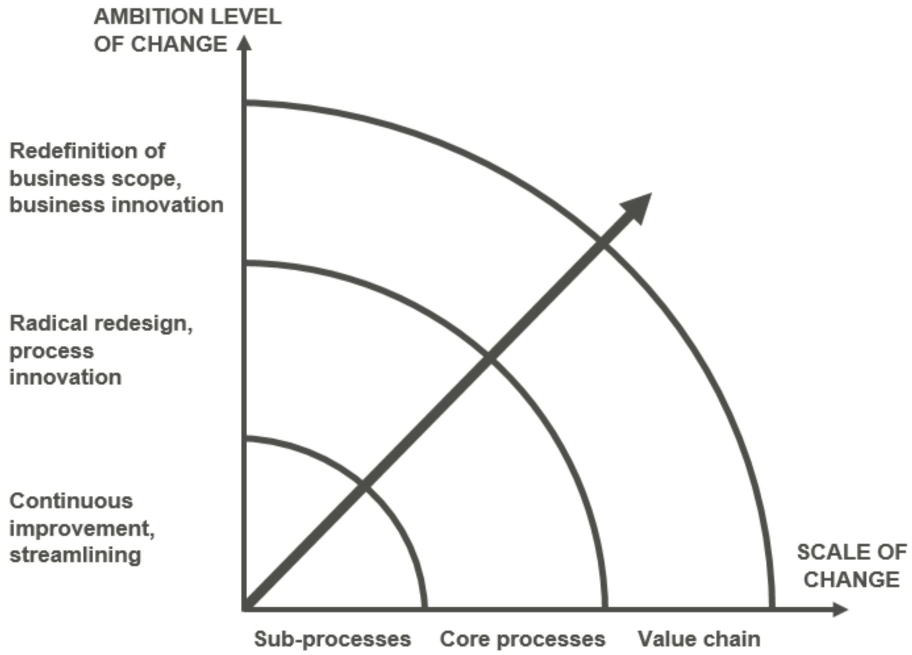

Figure 5.3 Challenge pattern of change (Translated from Hannus 1994, p.265).

Hannus (1994), however, notes that different ambition levels influence organizations differently and fit unequally into different situations (see Table 5.1). Continuous improvement usually focuses on sub-processes, and the aim is not to question the existing business processes, organizational structures, or ways of working. On the contrary, the starting point of radical redesign is the questioning of all existing business processes, organizational structures, and ways of working, which then turns into rationalization of existing business and rethinking them starting from level zero. The redefinition of business is the most extensive ambition level, since it will lead to a change of one or more fundamentals in the company's business, the fundamentals being the customer, the way of working, the products and the services (Hannus 1994). Finally Hannus (1994) states that innovative use of information and communication technology is very often related to redefinition of business scope. (Hannus (1994, pp.16−102)

Table 5.1 Different ambition levels fit unequally into different re-engineering situations (Translated from Hannus 1994, p.16).

Levels of re-engineering	Situation where ambition level fits
Continuous improvement	- Change in environment is slow and/or predictable - Competitors operations are predictable - Engaging the whole staff to change
Radical redesign of processes	- Change in environment is rapid - Rapid and unpredictable operations of competitors - Top management as initiator
Redefinition of business scope	- New business based on new technologies - Spin off -actions in large companies

Hannus (1994, p.341) states that one of the main challenges in business transformation is efficient management of transition phase where company moves from existing processes, structures and ways of working to a totally new way of operating in the industry (see Figure 5.4). Figure 5.4 provides an answer for the fourth question, since during the transition phase the company's performance declines dramatically, and this known fact needs to be taken into account when change implementation is being prepared.

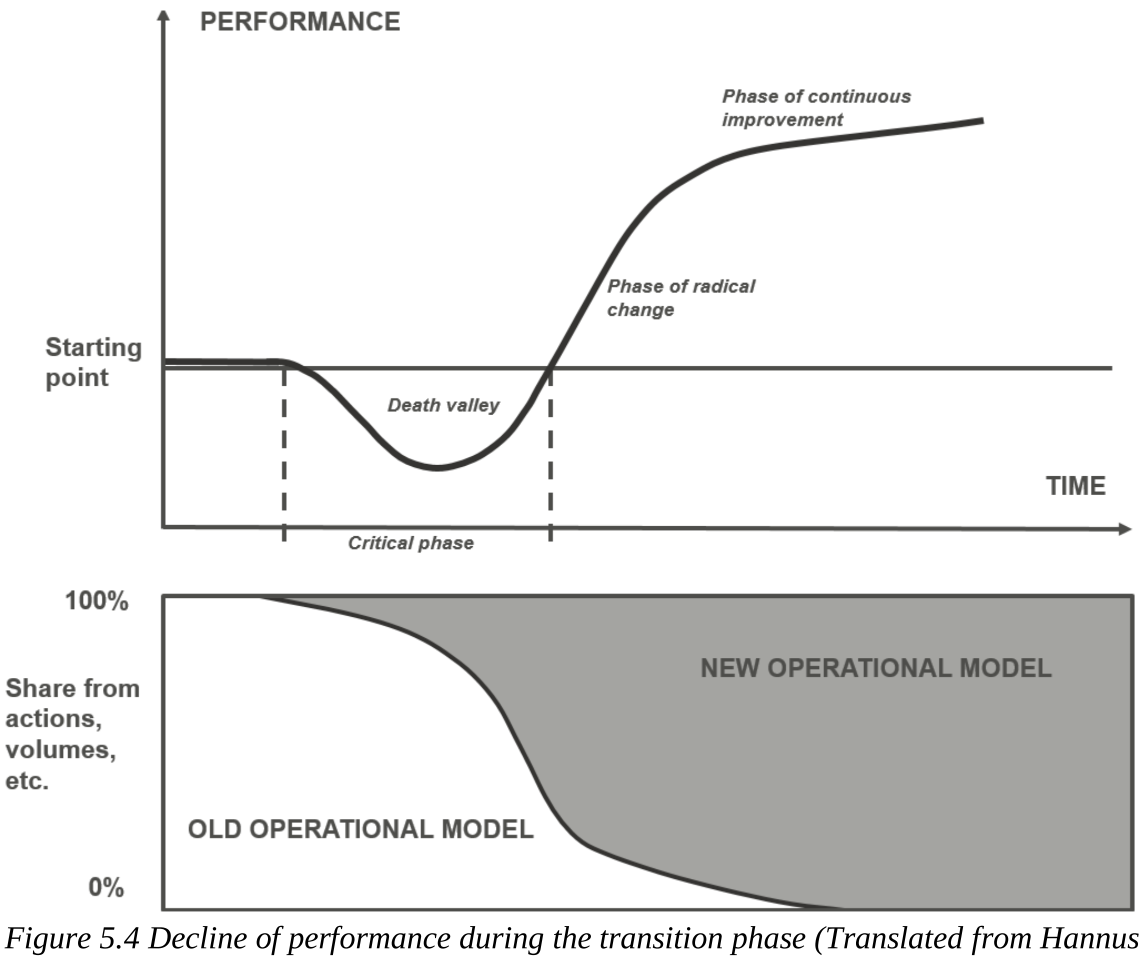

Figure 5.4 Decline of performance during the transition phase (Translated from Hannus 1994, p.341).

The basic idea behind the evaluation stage is to provide a general picture about the BIM implementation process, upcoming challenges and how to prepare for them. This information can be shared with the whole organization from designer to top management. According to Coates et al. (2010, p.4), evaluation helps determine the roadmap and the resources for the BIM adoption and identify the efficiency gains of BIM adoption. If the evaluation stage is conducted properly, the company is well prepared for the actual implementation. They know when to allocate resources and how much resources are needed for smooth and successful implementation of BIM.

5.2.2. Object-based modeling

In the first BIM stage of Succar's (2009; 2010a) framework, companies create single-discipline models either in design, construction or operation phase of the project, and the deliverables are, for example, architectural models, engineering models or fabrication models, which are then primarily used to automate the generation and coordination of 2D documentation or 3D visualization. The first stage of the BIM implementation process for structural precast fabricators is very similar, and in practice it would mean that BIM software is being implemented in one of the project phases, which could be for example the bidding phase, design phase or construction phase. Generally in all of these phases the model is being created by the design department of the structural precast fabricator, but in some cases it is also possible that a sales engineer, for example, creates a simple sales model for bidding purposes to obtain quantity take-offs for the tender.

Deliverables in the first BIM stage consist of basic data exports and light-weight 3D models which do not have any modifiable parametric attributes (Succar 2009, p.364; Succar 2010a, p.7). Deliverables for structural precast fabricators are quite the same in the first stage of the BIM implementation process. In practice, the basic data export deliverables can include different quantity take-offs and material lists as well as 2D drawings and light-weight 3D models, 3D PDFs and erection sequence visualizations, for example.

According to Succar (2009, p.364; 2010a, p.7), collaboration practices in the first BIM stage are similar to the Pre-BIM stage, which means that there are no significant model-based interchanges between different disciplines and that communication is based on 2D documentation. The data exchange between project parties is one-directional, which continues the asynchronous and disjointed communication between the parties. Collaboration practices are similar also in the first stage of the BIM implementation process, which means that structural precast fabricators are still collaborating and communicating according to a drawing-based process. Although, in some situations 3D models are used instead of or with the 2D documents; for example when assembling complicated reinforcements to molds or erecting precast concrete elements on site.

Since only minor process changes occur in the first BIM Stage, the contractual relations, risk allocations, and organizational behavior persist the same as in the Pre-BIM phase, but object-based modeling encourages fast-tracking of the project phases, and when projects are still executed in a phased manner, there is eagerness to overlap the design and construction activities to save time (Succar 2009; Succar 2010a). Figure 5.5 is a linear illustration of the project lifecycle phases in the first BIM stage where overlap between the different phases does not exist. After structural precast fabricators have implemented BIM in one of the chosen departments, it is quite obvious that the achieved benefits in the department will drive the model-based activities forward also in other parts of the company.

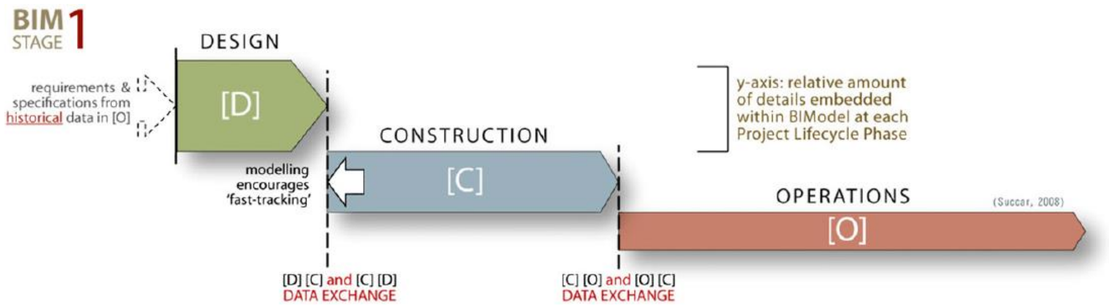

Figure 5.5 Project lifecycle phases at BIM stage 1 (Succar 2009, p.366).

According to Venkatraman (1994, pp.74–76), from re-engineering point of view, in the first stage of the BIM implementation process, companies implement information technology applications, which in this case refers to BIM software, with minimal changes to the business processes to respond to some operational problems or challenges. In addition, Hannus (1993, pp.231–232) adds that in the first level of the BIM implementation process, information technology solutions separated for certain purpose are used for organization's internal purposes. Both BIM and re-engineering theories support each other as they have very similar approaches to the first step of the BIM implementation process.

5.2.3. Model-based collaboration

When companies have developed single-disciplinary modeling expertise in the first BIM stage, they are able to start active collaboration with other disciplinary players on the second stage, and this collaboration may occur in many technological ways depending on each player’s set of BIM software tools (Succar 2009; Succar 2010a). After the first stage in the BIM implementation process, a department inside a structural precast fabricator has implemented BIM software as a part of their workflow, and in the second stage of the process the fabricator starts active collaboration between different departments inside the company. Since in most cases object-based modeling has been started by the design department of the structural precast fabricator, the internal disciplines that can then take part in model-based collaboration are the sales department (bidding purposes), fabrication department (manufacturing purposes), and site operations department (installation purposes).

The second stage alters according to the granularity of the modeling performed at each life cycle phase, as very detailed constructible models move forward and replace less detailed design models (Succar 2009; Succar 2010a). In the second stage of the BIM implementation process, deliverables are still quite the same than in the two previous stages, but more detailed constructible model information is being collaborated in the form of a model between the departments.

According to Succar (2009; 2010a), model-based collaboration can occur within one or between two project life cycle phases in the second BIM stage. Model-based collaboration can include both interchange of models or part-models through either proprietary or non-proprietary formats (Succar 2009; Succar 2010a). For structural precast fabricators, this means that the models created by the design office are then shared with sales, fabrication or site operations department. In most cases, collaboration between design and sales department requires full models, since the sales department requires data from the whole project. But when design office is collaborating with the other two departments, part-models are mainly preferred since the departments usually only work with some parts of the project, but then again, in the beginning they also need less detailed data from the whole project.

Succar (2009; Succar 2010a) notes that although the collaboration and communications between the BIM players continue to be asynchronous, pre-BIM demarcation lines that are separating the roles, disciplines and lifecycle phases start to fade. This leads to some contractual amendments becoming necessary, as model-based interchanges augment and start replacing drawing-based workflows and model-based collaboration instigates fast-tracking and changes the relative modeling intensity within each life cycle phase (Succar 2009; Succar 2010a). Figure 5.6 is a linear illustration of the project life cycle phases in the second BIM stage where some overlap exists between the project phases. For structural precast fabricators, this means that in the second stage of the implementation process they need to define rules and policies for collaboration, not only for the model creation. Structural precast fabricators also need to re-engineer their processes according to model-based workflow if they want to fully realize the benefits of BIM implementation.

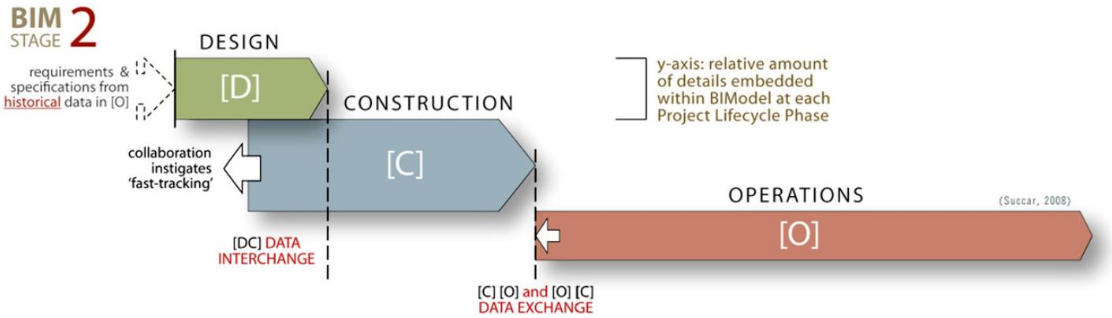

Figure 5.6 Project life cycle phases at BIM stage 2 (Succar 2009, p.366).

According to Venkatraman (1994, p.76), from re-engineering point of view, the second BIM stage reflects more systematic attempt to implement information technology throughout the entire business process. This second stage involves both technical interconnectivity and business-process interdependence because neither of these are sufficient alone and the benefits of information technology implementation are not fully realized if information technology is superimposed on the current business processes (Venkatraman 1994, pp.76−79). However, according to Hannus (1994, pp.231−232), in the second BIM stage, information technology integration inside the company, without questioning the existing business structure and processes, should be the right way to implement information technology. Since structural precast fabricators have performed evaluation before starting actual BIM implementation process, they have the knowledge of which of the processes they need to change when integrating BIM software as a part of internal workflow, to achieve desired level of efficiency.

5.2.4. Network-based integration

In the third BIM stage, integrated information-rich models are created, shared and maintained collaboratively across all project life cycle phases through different model-server technologies, databases and/or Software as a Service (SaaS) solutions (Succar 2009; Succar 2010a). According to Succar (2009, p.365), the prerequisite for this stage is the maturity of the network and software technologies that allow a shared interdisciplinary model to provide two-way access to project parties. This means that in this stage of the BIM implementation process, structural precast fabricators create, share and maintain integrated models with other project parties and internally with other departments.

In the third BIM stage, models become interdisciplinary nD models that allow complex analyses in early stages of design and construction (Succar 2009; Succar 2010a). Succar (2009, p.365) states that deliverables of these interdisciplinary nD models extend beyond traditional object properties to include business intelligence, lean construction principle, green policies, and whole life cycle cost-estimations. For the BIM implementation process, this means that structural precast fabricators need to take into account the different needs regarding the deliverables that other project parties have, and these demands also probably appear much earlier compared to projects being led according to drawing-based process needs.

Interdisciplinary nD model is in the center of project coordination, and collaborative work spirals iteratively around it (Succar 2009; Succar 2010a). In the BIM implementation process, this means that structural precast fabricators need to modify their processes to fit the new kind of demands of project collaboration and information needs.

According to Succar (2009; Succar 2010a), synchronous interchange of model and document-based data causes project life cycle phases to overlap extensively, which ultimately leads to a phaseless process (see Figure 5.7). Network-based integration leads to concurrent construction where all project activities are integrated and all aspects of design, construction and operation are concurrently planned to maximize the value of objective functions while optimizing constructability, operability and safety (Succar 2009, p.365). Succar (2009, p.365) notes that implementation of the third BIM stage necessitates major reconsideration of contractual relationships, risk-allocation models, and procedural flows. Third stage in the BIM implementation process concentrates on the policies especially from a networking point of view. There are some necessary changes to existing processes since Pre-BIM policies and workflows no longer work in the new kind of collaboration environment of network-based integration.

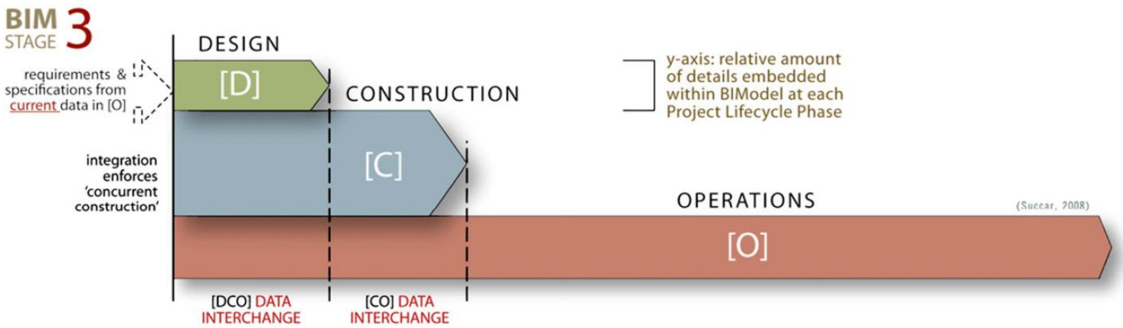

Figure 5.7 Project life cycle phases at BIM stage 3 (Succar 2009, p.367).

Venkatraman (1994, p.79) notes that the previous stages of re-engineering and BIM have focused on business transformation within a single organization or company, but the third re-engineering stage includes multiple participants focusing to redesign the business network and enhance it through implementation of information technology capabilities. According to Hannus (1994, p.231−232), the starting point of this re-engineering stage is the redesign of existing core processes and structures, which can be done either internally or in collaboration with other companies. From a re-engineering point of view, in the third stage of the BIM implementation process, structural precast fabricators need to start the re-engineering efforts in collaboration with other project parties. Finally, the maturity of technologies, processes and policies eventually facilitates Integrated Project Delivery (IPD) (Succar 2009, p.365).

5.2.5. Integrated Project Delivery

According to Succar (2009; 2010a) Integrated Project Delivery (IPD) is a suitable term to represent the long-term vision of BIM as a merger of domain technologies, processes and policies. The loosely defined IPD can be seen as the goal of the BIM implementation process that starts from the fixed Pre-BIM point and continues through three well-defined BIM stages. Succar (2009; 2010a) attempts to include all pertinent BIM visions in his framework. For structural precast fabricators, the last stage of the BIM implementation process can be seen as the goal of the future where the leading companies of the industry position themselves when technology, processes, and policies are not at the level that IPD requires.

From a re-engineering point of view, the last stage of BIM implementation process represents the redefinition of a company’s business idea and scope, and both of these things should be evaluated based on new information-technology capabilities (Hannus 1994, pp.231−232). According to Venkatraman (1994, pp.83−84), in this stage companies need to carry out strategic analysis where they question the businesses involved and why to define what kind of role, if any, information technology will play in this redefinition.

5.3. BIM implementation guideline

This chapter introduces the parts and content of the BIM implementation guideline. All parts of the guideline and its content are being explained, defined, and modified according to the needs of structural precast fabricators. The main purpose of this chapter is to validate how Succar’s (2009, 2010a, 2010b, 2012) BIM implementation framework fits into structural precast fabricators' BIM implementation needs.

5.3.1. Evaluation indicators

Venkatraman (1994, p.74) suggests that the first thing that every company should do when starting information technology-enabled business transformation is to identify and decide the level of transformation where the benefits are in line with the potential costs and efforts that are needed for organizational changes. In addition, Coates et al. (2010, p.3) states that before starting the actual re-engineering implementation and creating an adoption strategy for it, the companies need to make some decisions to identify the scope and the characteristics of the implementation. Based on the findings above, which are just some examples from both literature reviews, it was clear that some kind of evaluation before the actual BIM implementation was needed to map the potential costs, need of labor, and scale of change.

While considering possible indicators, it became clear quite quickly that there is no single indicator that could help in creating the gap analysis but that several indicators are needed to fully evaluate the gap between status quo and future target of the company. Suitable indicators for structural precast fabricators were found in Succar's (2009; 2010a) BIM implementation framework.

Succar (2009, 2010a) has identified three BIM Fields, which are Technology, Process and Policy, and three BIM Stages, which are Object-based Modelling, Model-based Collaboration, and Network-based Integration, in his BIM implementation framework. When these two are combined, there are three valid indicators that can be used to perform the gap analysis.

The first indicator of the gap analysis is combined from the Technology aspect of BIM Fields and the Object-based Modelling aspect of BIM Stages. According to Succar (2009, p.364), in Object-based Modelling stage data is still being generated and used by individuals, teams or units inside companies. For structural precast fabricators, this means that the design office or subcontracted company uses BIM inside their unit, but the process they use is still drawing-based. In addition, this means that from the BIM Fields aspect there is no process or a network yet developed, and technology is the only aspect that is used and especially the BIM software part of it. Figure 5.8 represents the first indicator of the gap analysis.

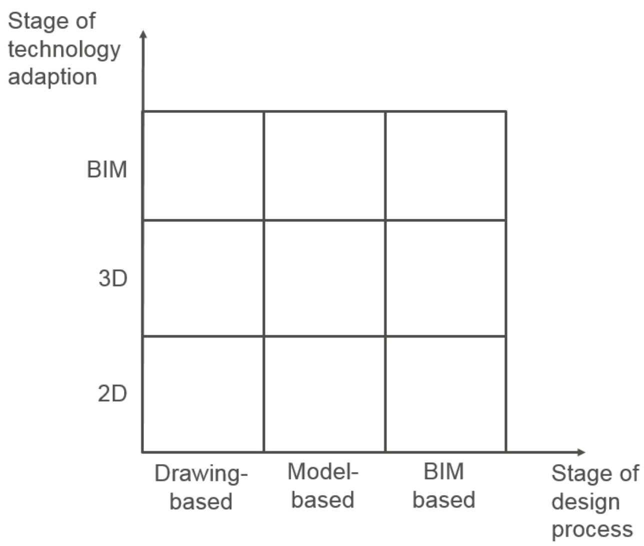

Figure 5.8 Indicator of design process gap. In this indicator, x-axis presents the stage of design process (drawing-based, model-based or BIM-based), and y-axis the stage of technology adoption (2D, 3D or BIM).

X-axis in Figure 5.8 presents the stage of design process in the company. In drawing-based stage, design is done with 2D CAD software and the design process and communication between project parties are fully dependent and based on drawings. In model-based stage, design is done either with 3D CAD or BIM software but the process and communication between project parties are still heavily based on drawings. Finally in the BIM-based stage, design is done with BIM software and the design process and communication between project parties are based on model information, which can be provided from the building information model. Y-axis in Figure 5.8 presents the stage of technology adoption in the company. In the 2D stage, the company’s processes are based on the 2D way of working where drawings, contracts, and other paper documents rule the business and decision-making. In the 3D stage, the company’s processes are still heavily based on the 2D way of working as was the case in the previous stage, but in some parts of the processes the company already uses the 3D models created. In the BIM stage, the company’s processes are redesigned in a way that they are able to use and benefit more of the data that is available in the building information model.

The second indicator of the gap analysis is combined from the Process aspect of BIM Fields and from the Model-based Collaboration aspect of BIM Stages. According to Succar (2009, p.364), in the Model-based Collaboration phase individuals, teams or units actively collaborate with other disciplines. For structural precast fabricators, this can mean a couple of different collaboration options: firstly, collaboration can take place between fabricator’s design unit and other design disciplines such as architects or engineers; secondly, collaboration can take place between a design unit and a construction unit, which includes procurement, production and erection units; and thirdly, collaboration is possible between the design unit and the project owner who uses the model data for facility maintenance. This gap analysis concentrates on internal collaboration between the design unit and the construction unit. From the BIM Fields aspect, technology is already in use and process creation has started, but the network has not yet developed. Figure 5.9 represents the second indicator of the gap analysis.

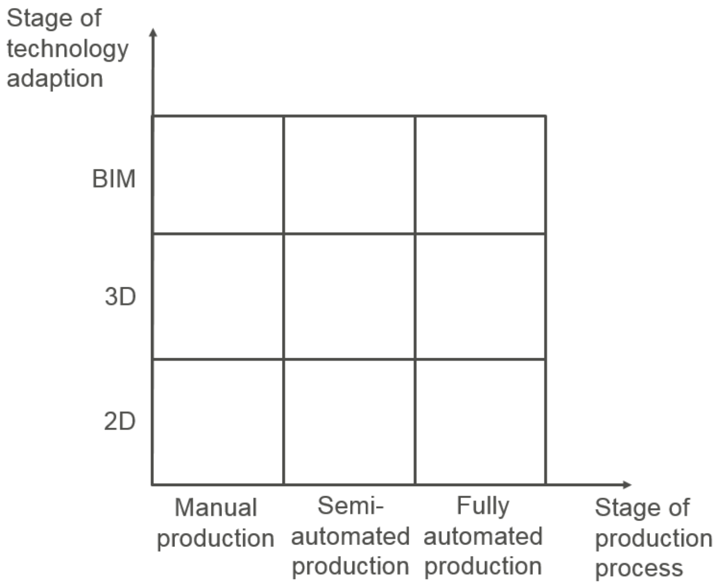

Figure 5.9 Indicator of production process gap. In this indicator, the x-axis presents the stage of the production process (manual production, semi-automated production, or fully automated production), and the y-axis presents the stage of technology adoption (2D, 3D or BIM).

X-axis in Figure 5.9 presents the stage of the production process in the company. In manual production, the stage manufacture of the precast elements is done manually and the manufacture of elements is done according to drawings that are received from the design department. In a semi-automated production stage, the manufacture of the precast elements is partly done manually and some parts of the manufacture process have been automated, since model data from 3D or BIM enables some automation, for example, the reinforcing bars, meshes and cages can be produced with dedicated machinery and just assembled into the mold before casting the concrete. In the fully automated production stage, the manufacture of the precast elements is done by sophisticated machinery and skilled human labor is not needed to manufacture precast elements because machinery takes care most of the critical manufacturing tasks. Y-axis in Figure 5.9 is exactly the same as in Figure 5.8.

The third indicator of the gap analysis is combined from the Policy aspect of BIM Fields and from the Network-based Integration aspect of BIM Stages. According to Succar (2009, p.365), in the Network-based Integration phase individuals, teams and units in different companies create, share and maintain information-rich building information models. From the BIM Fields aspect, technologies as well as the process are present and in use, but correct policies such as contracts and regulations have not yet developed to the level where they should be. Figure 5.10 represents the third indicator of the gap analysis.

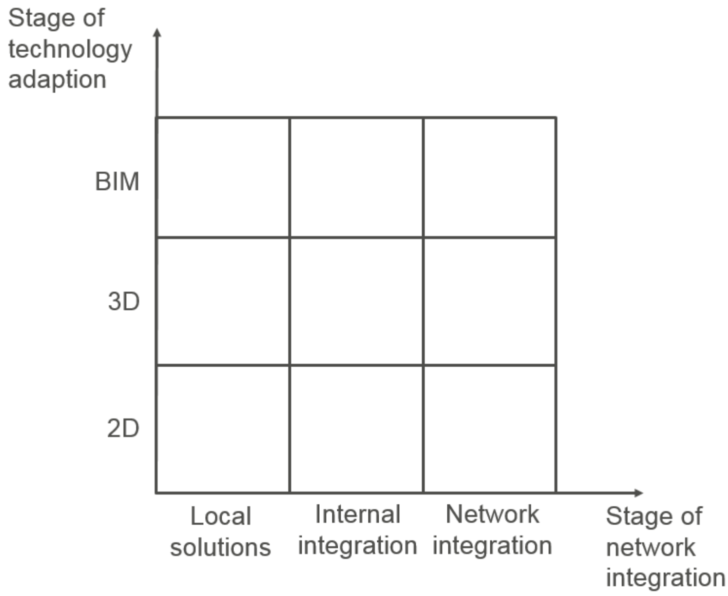

Figure 5.10 Indicator of network integration gap. In this indicator, the x-axis presents the stage of network integration (local solutions, internal solutions, or network integration) and the y-axis presents the stage of technology adoption (2D, 3D or BIM).

X-axis in Figure 5.10 presents the stage of network integration in the company. In local solutions, stage networking and knowledge sharing are limited to some parts of the company, for example, to a design department, where information and knowledge are shared effectively, but not outside the department. In the internal integration stage, networking and knowledge sharing are done internally inside the company but information and knowledge are not shared outside the company, for example with partners or project parties. In the network integration stage, networking and knowledge sharing are done among the whole value chain of the company including partners and project parties. Y-axis in Figure 5.10 is exactly the same as in Figure 5.8.

Based on these three indicators, it is possible to perform evaluation of the current phase of the company as well as the future target and estimation of implementation’s workload. Figure 5.11 depicts an example of how these three indicators can be used when evaluating the impact of BIM implementation in the company. When using these indicators, the company has to mark two dots on every indicator which then indicate current status (red dot) and future target (blue dot). In addition, based on this information it is possible to illustrate the gap of the implementation (grey arrow) and the approach on how to start and execute the implementation (two dotted grey lines).

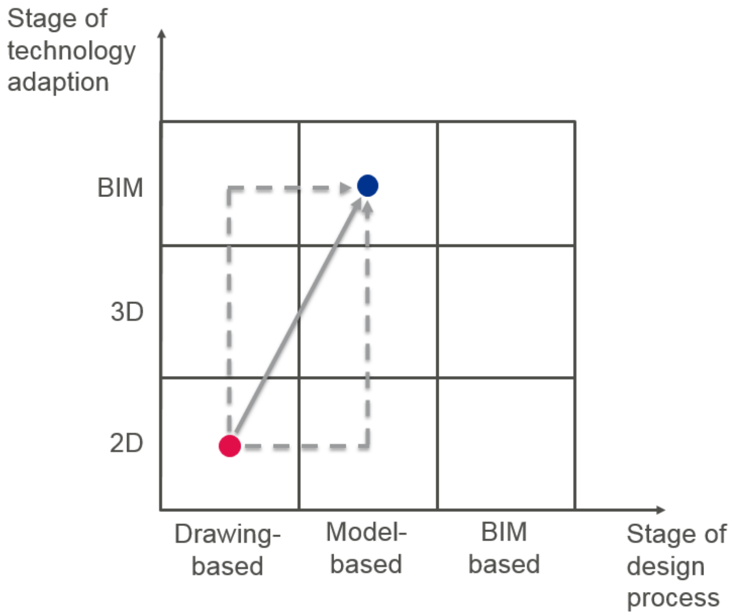

Figure 5.11 Example of how to use the three evaluation indicators. The red dot indicates the status quo in the company, and the blue dot indicates the future target of the company. The grey arrow represents the gap between status quo and future target and the change that needs to take place during the implementation process. The two dotted grey lines represent the alternative ways to approach the implementation.

The first indicator (see Figure 5.8) illustrates the gap between the amount of resources and efforts needed in the first phase of the implementation when BIM is usually only implemented in one part of the company, for example, in the design department. The second indicator (see Figure 5.9) illustrates the amount of resources and efforts needed in the second phase of the implementation when BIM is being implemented in multiple departments inside one company and data from the building information model should flow smoothly between different departments. The third indicator (see Figure 5.10) illustrates the amount of resources and efforts needed in the third phase of the implementation when BIM is being implemented in the workflow between two or more companies to achieve more efficient and error-free workflow with the model data.

This relatively simple evaluation method illustrates three things for the companies that are in the process of considering BIM adoption: what is the company's current situation on these three fields, what is the company's future target, and what kind of gap exists between these two points. The first two things can be used to evaluate company's situation in the market: how competitors are situated in these three indicators, is it possible to gain more market share with BIM adoption, and are there new business opportunities involved in this new technology and way of working. Evaluation of these three indicators will also illustrate where and when the biggest challenges occur during the implementation process.

This evaluation provides a good starting point for the creation of a BIM implementation plan, since after the evaluation phase, the resources needed, the volume of change, and several other things can already be roughly estimated. As a summary, it can be said that as a result of the evaluation phase there should be a clear plan for implementation, which will then define the schedule, the human resources needed, and other possible resources needed for successful BIM implementation.

5.3.2. BIM Fields

Succar (2009; 2010a) has identified three interlocking yet distinctive BIM Fields of activity which comprise the BIM domain (see Figure 5.12). Technology, Process and Policy are the three BIM Fields, and players, deliverables and requirements are the three sub-fields in Succar's framework. Identification of the BIM Fields was done using conceptual clustering of observable knowledge objects within the AECO industry, and when these Fields interact within the industry, new products, services and roles are being generated (Succar 2010a, p.4).

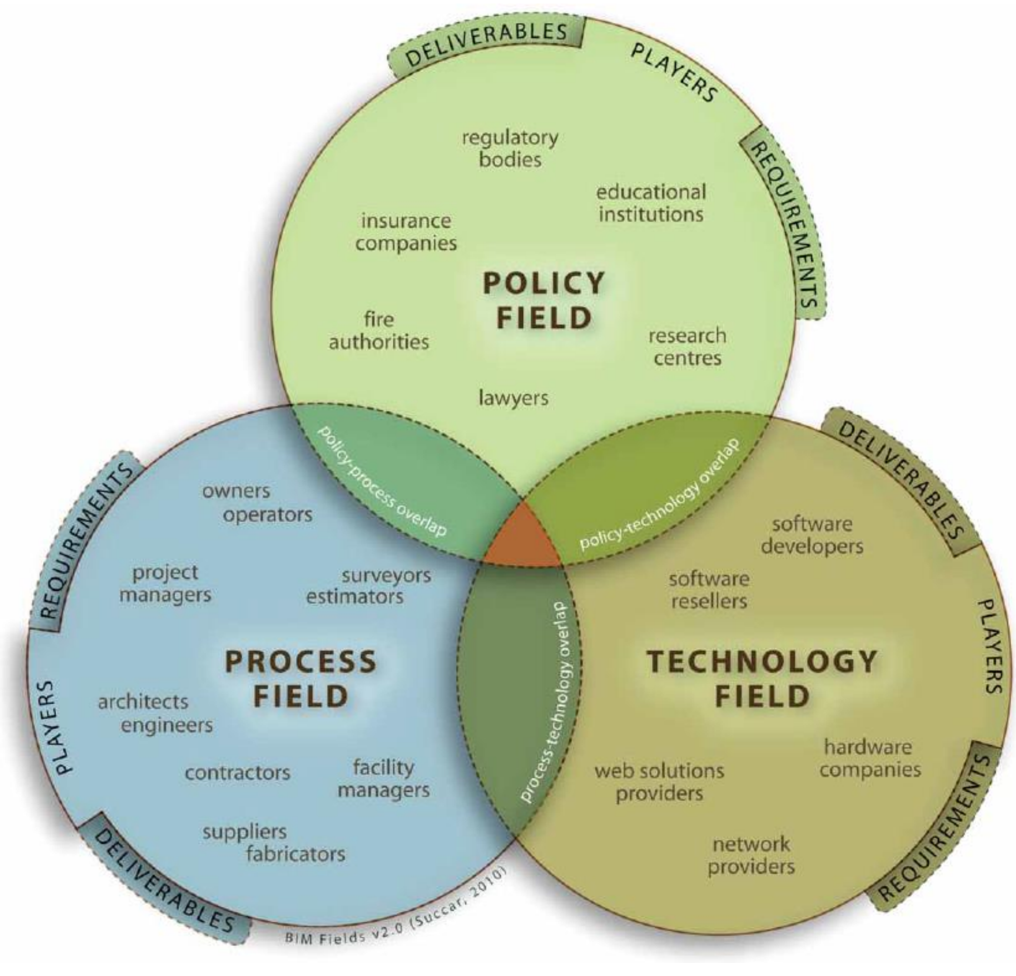

Figure 5.12 The interlocking fields of BIM activity (Succar 2012, p.122).

The Technology Field forms a group of players who increase the efficiency, productivity and profitability of AECO sectors. This group of players is specialized in developing the necessary software, hardware, equipment, and networking systems. Facility owners, architects, engineers, contractors and facility managers are the players in the Process Field, and they produce, design, construct, manufacture, use, manage and maintain the structures built by the AECO sector. The Policy Field forms a group of players who actually do not generate any construction products but are specialized organizations that play crucial preparatory, regulatory and contractual roles in the design, construction and operations process. In other words, these players in the Policy Field are focused on preparing practitioners, delivering research, distributing benefits, allocating risks, and minimizing conflicts within the AECO sector. Insurance companies, research centers, educational institutes, and regulatory bodies are some examples of the players in the Policy Field. (Succar 2009; Succar 2010a)

Within or between the BIM Fields and sub-fields occur push-pull knowledge transactions (see Figure 5.13). These transactions can include, for example, data transfers, team dynamics, and contractual relationships between the Fields and sub-fields. According to Succar (2009, 2010a), in a push-mechanism, knowledge is being transferred to another Field or sub-field, while in a pull-mechanism, knowledge is being transferred to satisfy a request by another Field or sub-field. (Succar 2009, p.360)

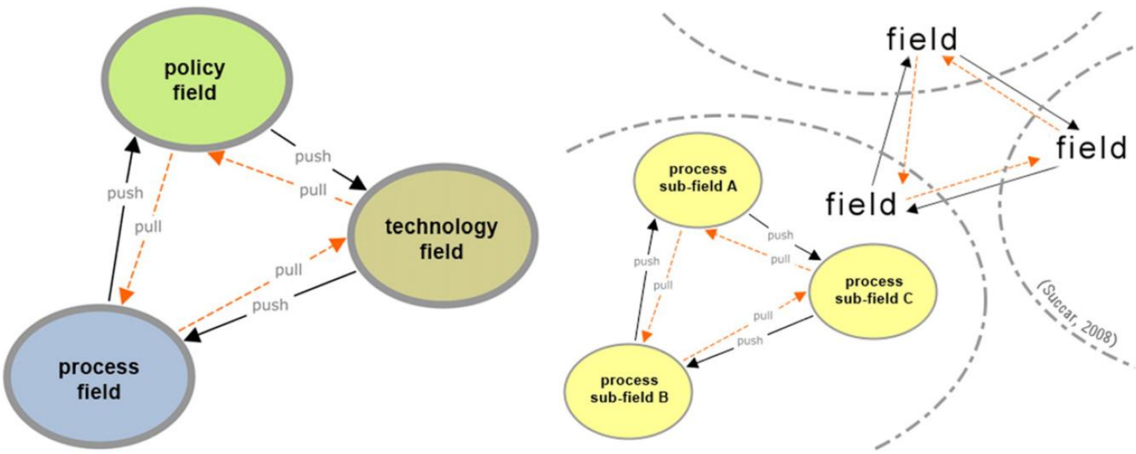

Figure 5.13 BIM interactions between and within Fields and sub-fields (Succar 2009, p.361).

The starting point of Succar's BIM Fields creation has been the whole AECO sector, while this research only concentrates on one industry in the AECO sector. In addition, the BIM implementation process for structural precast fabricators only concentrates on one company and its value chain at a time. For this reason, the BIM Fields are not suitable as they are, and they need to be modified to fit the structural precast industry. A more suitable theory was found during the second literature review. According to Peppard & Rowland (1995, pp.45−46), all organizations are built on three main pillars, and when companies start to redesign their processes, these three elements (people, process, technology) must be aligned with the needs of the market and the customers within it, as well as with each other. In this study, the three main pillars of organization are used as the BIM Fields. The definition of the Technology Field in the BIM implementation process is exactly the same as Succar's definition of the Technology Field in his framework, and the Technology Field is mainly composed of technical things that affect the BIM implementation process. The definition of the Process Field in the BIM implementation process is similar to Succar's definition of Policy Field in his framework, and the Process Field is mainly composed from contractual and regulatory things that affect the BIM implementation process. The definition of the People Field in the BIM implementation process is similar to Succar's definition of the Process Field in his framework, and the People Field is mainly composed of the things that affect the people who are part of the BIM implementation process. More detailed definition and content of each BIM Field used in this study is presented in later chapters.

5.3.3. BIM Steps

Succar (2009; 2010a) has discovered several BIM Steps that are instrumental in enabling organizations and individuals to increase their BIM capability and maturity in a systematic way. According to Succar (2010a, p.12), each BIM Stage has its own requirements and deliverables giving rise to numerous BIM Steps. BIM Steps can be identified in accordance with their location on Succar's continuum (see Figure 5.14).

Figure 5.14 BIM Steps leading to or separating BIM Stages (Succar 2009, p.368)

According to Succar's (2009; 2010a) definition, all steps follow each other linearly. All BIM Steps are then further divided into sets of steps that are based on the BIM Fields (see Figure 5.15).

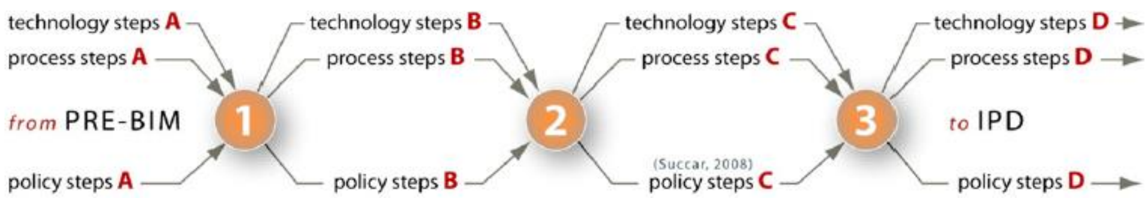

Figure 5.15 BIM Step sets leading to or separating BIM Stages (Succar 2009, p.368)

Since the volume and complexity of changes in the BIM Stages are transformational, they cannot be implemented without these traversing incremental evolutionary steps (Succar 2009; 2010a). The BIM Steps and Step sets that Succar has discovered in his BIM framework fit as such in the BIM implementation process. The only things that need slight corrections are the names of the Step sets as different BIM Fields are being used in the BIM implementation guideline.

5.3.4. BIM Maturity Index

According to Succar (2010b; 2012), BIM Maturity refers to the quality, repeatability and degree of excellence within the BIM Stages. Succar (2010b; 2012) has developed a BIM Maturity Index that has been customized to reflect the specifics of BIM capability: implementation requirements, performance targets, and quality management (see Figure 5.16).

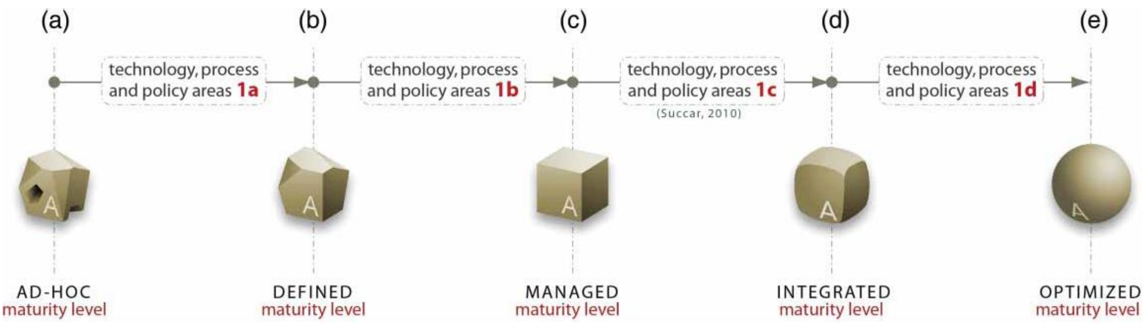

Figure 5.16 BIM Maturity levels at BIM Stage 1 (Succar 2009, p.368).

Succar's (2010b; 2012) BIM Maturity Index has five distinct levels: (a) Ad-hoc, (b) Defined, (c) Managed, (d) Integrated, and (e) Optimized. Progression from low to higher levels of maturity indicate: (i) better control through minimizing variations between performance targets and actual results, (ii) better predictability and forecasting by lowering variability in competency, performance and costs, and (iii) greater effectiveness in reaching defined goals and setting new more ambitious ones (Succar 2010b; Succar 2012). BIM Maturity Index, which Succar has developed in his BIM framework, can be used as such in the BIM implementation guideline without any changes.

5.3.5. BIM Competency sets

In previous chapters, the BIM Fields as well as BIM Steps, which were derived from the BIM Fields, were introduced, and in this chapter, the BIM Fields are further divided into more manageable sections called BIM Competency sets (see Figure 5.15). According to Succar (2010a; 2010b; 2012), BIM Competency represents a BIM player's ability to satisfy a BIM requirement or generate a BIM Deliverable (see Figure 5.12), and it is a hierarchical collection of individual competencies identified for the purposes of BIM implementation and assessment.

Succar's (2010a; 2010b; 2012) BIM Competency sets follow the same classification as BIM Fields: Technology BIM Competency sets are Software, Hardware and Networks; Process BIM Competency sets are Leadership, Infrastructure, Human Resources and Products & Services; and Policy BIM Competency sets are Contracts, Regulations and Research & Education. Since BIM Competency sets follow the classification of BIM Fields, it is not possible to use this classification as such, but it has to be modified according to the BIM Fields used in the BIM implementation process.

Process, People and Technology are the BIM Fields in the BIM implementation guideline, and based on Succar's framework, the BIM Competency sets will follow that classification, which then leads to following the BIM Competency sets: Process BIM Competency sets are Contractual, Regulatory, Infrastructure and Products & Services; People BIM Competency sets are Leadership, Human Resources and Education; and Technology BIM Competency sets are Software, Hardware and Networks.

5.3.6. Organizational scale

In the construction industry, each project is a unique prototype involving a similar set of process stages, and this uniqueness is driven by multiple factors, including the transient nature of project teams and the distinctive locational and environmental criteria of each project site. This challenge is addressed by the BIM Framework through the development of a granular Organizational Scale (see Figure 5.17). (Succar 2010a, p.13)

Low Detail Name	Sym	Granularity	High Detail Name	Sym	Granularity	Short Definition
MACRO Markets and Industries	**M**	Markets 1	(Macro M)	**M**	Market 1	Markets are the "world of commercial activity where goods and services are bought and sold" http://bit.ly/pjB3c
			(Meso M)	**Md**	Defined Market 2	Defined Markets can be geographical, geopolitical or resultant from multi-party agreements similar to NAFTA or ASIAN.
			(Micro M)	**Ms**	Sub-Market 3	Sub-markets can be local or regional.
	I	Industries 4	(Macro I)	**I**	Industry 4	Industries are 'the organised action of making of goods and services for sale'. Industries can traverse markets and may be service, product or project-based. The AEC industry is mostly Project-Based. http://bit.ly/ielY3
			(Meso I)	**Is**	Sector 5	A sector is a "distinct subset of a market, society, industry, or economy whose components share similar characteristics" http://bit.ly/15UkZD
			(Micro I)	**Id**	Discipline 6	Disciplines are industry sectors, "branches of knowledge, systems of rules of conduct or methods of practice". http://bit.ly/7jT82
				Isp	Specialty 7	Specialty is a focus area of knowledge, expertise, production or service within a sub-discipline.
MESO Projects and their teams	**P**	Project Teams 8	n/a	**P**	Project Team 8	Project Teams are temporary groupings of organisations with the aim of fulfilling predefined objectives of a project - a planned endeavour, usually with a specific goal and accomplished in several steps or stages. http://bit.ly/dqMYg
MICRO Organisations Units, their Teams & Members	**O**	Organisations 9	(Macro O)	**O**	Organisation 9	An organisation is a 'social arrangement which pursues collective goals, which controls its own performance, and which has a boundary separating it from its environment. http://bit.ly/v7p9N
			(Meso O)	**Ou**	Organisational Unit 10	Departments and Units are specialised divisions of an organisation. These can be co-located or distributed geographically.
				Ot	Organisational Team 11	Organisational Teams consist of a group of individuals (human resources) assigned to perform an activity or deliver a set of assigned objectives. Teams can be physically co-located or formed across geographical or departmental lines.
			(Micro O)	**Om**	Organisational Member 12	Organisational members can be part of multiple Organisational Teams.

Figure 5.17Granular Organizational Scale (Succar 2010a; Succar 2010b; Succar 2012).

According to Succar (2010a; 2010b), Organizational Scale can act as a BIM-scoping filter, and it can be applied to BIM players enabling a more targeted approach to BIM implementation and assessment. BIM players can be individuals, teams, organizations, or other possible sets of groupings (Succar 2010a, p.14). Succar's BIM frameworks

Organizational Scale principle can be applied as such to the BIM implementation guideline.

5.3.7. Visual BIM progress monitoring tool

According to Succar (2009, p.366), BIM Steps act as maturity levels within the BIM Stages, and BIM Steps assist in implementation efforts by identifying activities, services and products necessary to fulfil the requirements of the BIM Stages. Succar's BIM Steps matrix represents these visually, which aids in assessing an organization's maturity level, determining what steps have been accomplished or are still required (see Figure 5.18).

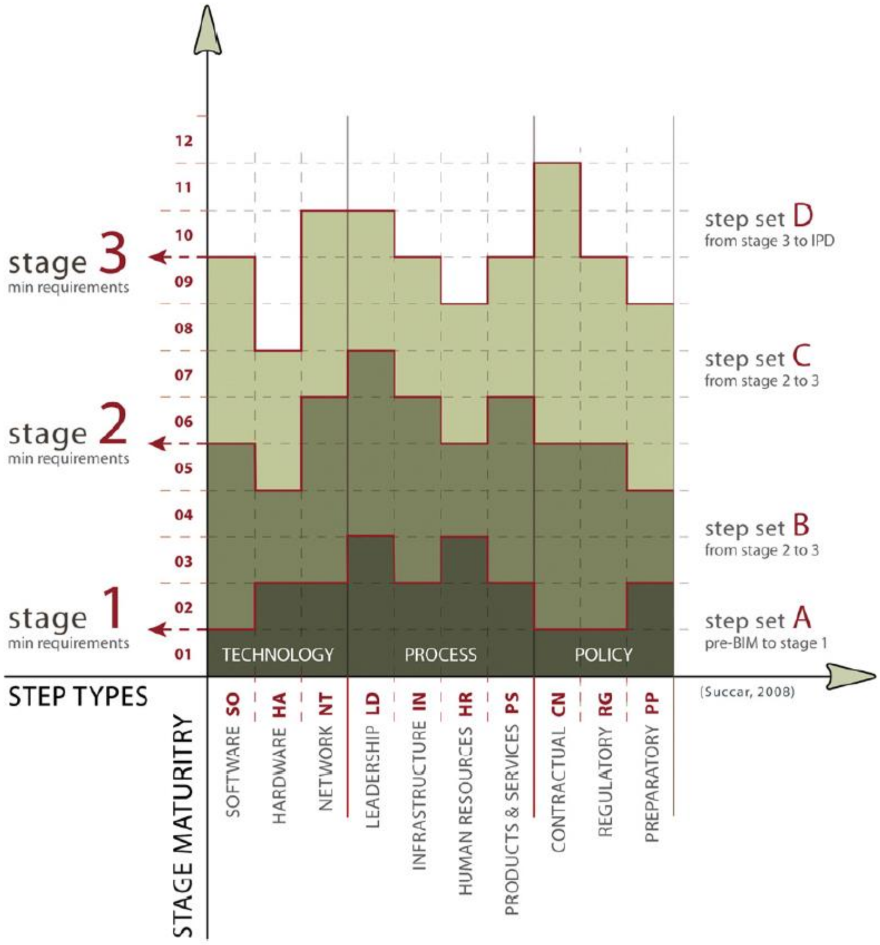

Figure 5.18 Generic BIM Step requirements for a BIM Stage in a matrix view (Succar 2009, p.370).

Figure 5.18 is a generic visualization of the BIM Steps matrix where x-axis holds the BIM Competency sets and y-axis the Organizational Scale. The progress of the BIM implementation can be defined with BIM Stages and BIM Steps. Figure 5.19 is a hypothetical presentation of an organization's BIM implementation efforts seen through Succar's BIM Steps matrix. The letter inside every progress step denotes the achieved maturity level of that step, which bases on the BIM Maturity Index, and color coding of the steps helps the visualization.

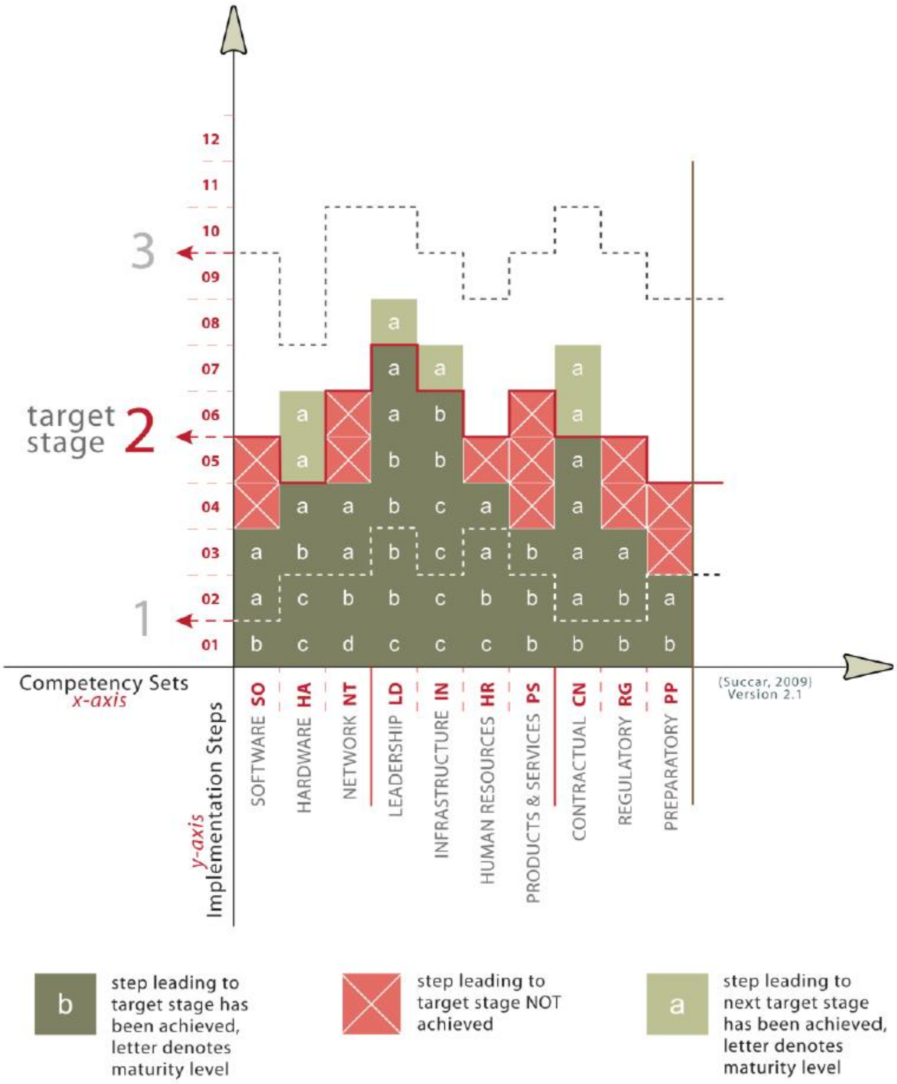

Figure 5.19 Tentative presentation of an organization's BIM implementation effort (Succar 2010a, p.40).

Succar's BIM Steps matrix can be used as such as a part of the BIM implementation guideline and as a visual implementation progress monitoring tool, since the same basic idea also works with the BIM implementation guideline, although some parts are different (see Figure 5.20). As discussed in previous chapters, in the BIM implementation guideline the BIM Fields and BIM Competence sets are different compared to Succar's BIM framework, but the differences do not prevent the use of the matrix.

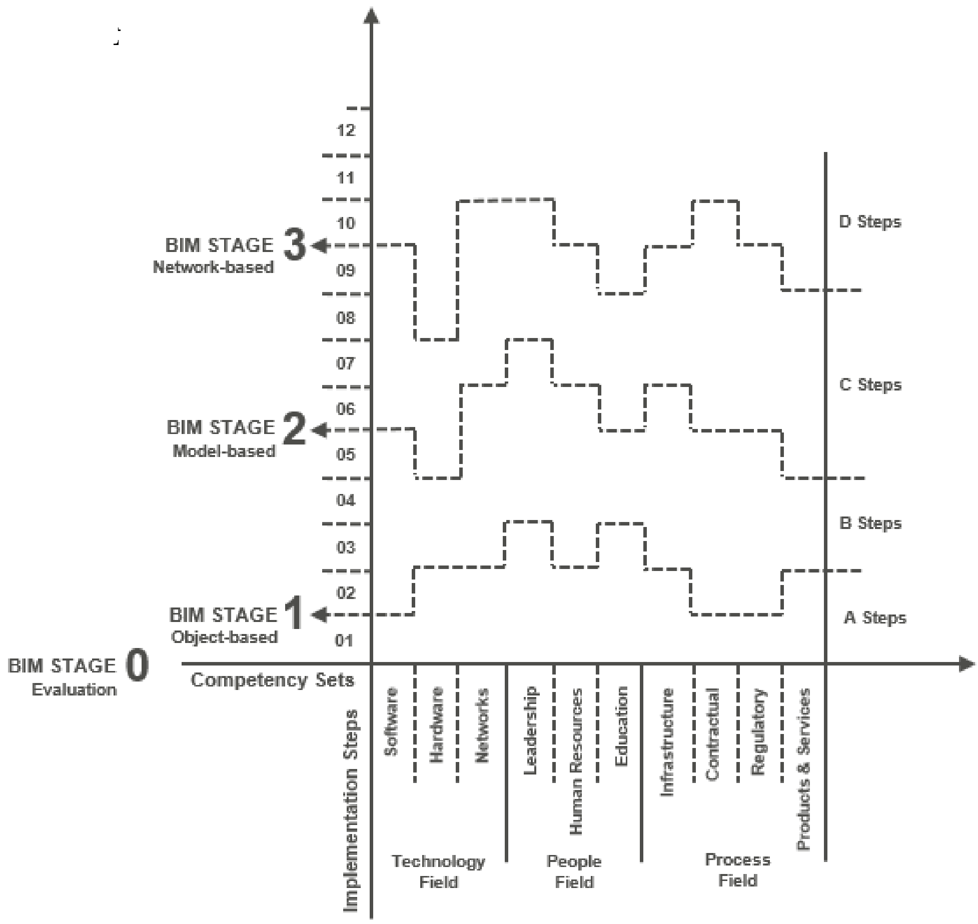

Figure 5.20 BIM implementation progress monitoring tool for BIM implementation guideline.

5.3.8. BIM progress scoring system

According to Succar (2010a, p.41), measuring BIM Capability and Maturity across markets, disciplines, and organizational volumes requires an extensive, consistent yet flexible scoring system. Succar (2010a, p.41) has developed the Maturity Discovery Score (see Figure 2.21) that is an exploration of the simplest form of scoring to be used for informal, self-administered assessments.

BIM Maturity Matrix Assessment at Granularity Level 1		a 10 Pts	b 20 Pts	c 30 Pts	d 40 Pts	e 50 Pts
Technology	Software			●		
	Hardware	●				
	Network		●			
Process	Leadership				●	
	Human Resources			●		
	Infrastructure		●			
	Products & Services		●			
Policy	Contractual		●			
	Regulatory			●		
	Preparatory				●	
Stage	Collaboration [2]			●		
Scale	Organisation [9]		●			
Subtotal		**10**	**100**	**120**	**80**	**0**
Total Points						**310**
Maturity Score						**25.83**

Figure 5.21 A Hypothetical Maturity Discovery Score (Succar 2009, p.370).

Succar's scoring system follows a simple arithmetic model that includes twelve individual scores, five maturity levels, and a discovery score. The twelve individual scores are composed of ten BIM Competency sets, one BIM Stage, and one Organizational Scale. Maturity levels are composed of a fixed number of maturity points which are: 10 points at level a, 20 points at level b, 30 points at level c, 40 points at level d, and 50 points at final level e. In the Maturity Discovery Score, all points are summed up to obtain the total points which are then subdivided by twelve to obtain the score. (Succar 2010a, p.41)

Succar's Maturity Discovery Score as such does not fit in to the BIM implementation guideline, and presumably it originates in Succar trying to create a scoring system that the whole industry could use in its BIM implementation efforts, and since the BIM implementation guideline is especially created for the structural precast industry, it will be used by one company at a time. The principle and idea behind Succar's scoring system is suitable for the BIM implementation guideline as such, and for that reason the author has generated a similar kind of scoring system that can be used by structural precast fabricators in their BIM implementation efforts (see Figure 5.22).

BIM progress score		Step 01 1 Pt	Step 02 2 Pts	Step 03 3 Pts	Step 04 4 Pts	Step 05 5 Pts	Step 06 6 Pts	Step 07 7 Pts	Step 08 8 Pts	Step 09 9 Pts	Step 10 10 Pts	Step 11 11 Pts	Step 12 12 Pts
Technology	**Software**												
	Hardware												
	Network												
People	**Leadership**												
	Human Resources												
	Education												
Process	**Infrastructure**												
	Contractual												
	Regulatory												
	Products & Services												
	Subtotal	0	0	0	0	0	0	0	0	0	0	0	0
												Total	0
												BIM progress score	**0**

Figure 5.22 BIM progress score tool for BIM implementation guideline.

6. CONCLUSIONS

This chapter explains the key results and their meanings and discusses the conclusions that can be drawn based on the research from theoretical and practical viewpoints. Some concrete procedures and recommendations as well as limitations to this study are given based on the results. The chapter finally lists possible future research and development paths that were identified during the study.

6.1. Theoretical and managerial contributions

The abstract nature of both BIM and re-engineering represent the theoretical gap of this study. Most of the BIM frameworks offer high-level information regarding the requirements and bigger thematic entities that companies should perform, especially from a technology point of view during the implementation, but they do not advice in which order steps should be taken and how to take into account the process point of view as well as the human aspect from a change management point of view. Thus, the results of implementation efforts have been variable and often or almost always the targets have not been achieved. The case interviews supported the theory findings as companies concentrate more on the technology side of things and tend to unintentionally forget the process and human aspect of the implementation. More practical guidelines are needed for BIM implementation to show how companies should first evaluate the impact as well as to show how to navigate through the implementation till the desired stage of BIM has been reached. As the BIM framework theories focus more on the technology side of things, the re-engineering theories focus on the process and human side of things, where technology is seen as an enabler of new improved business processes.

The primary theoretical contribution of this research is the merging of the BIM framework created by Succar into different re-engineering frameworks created by Hannus and Venkatraman. To date, some discussion exists within BIM literature regarding re-engineering in BIM implementation, but so far any of those discussions have not looked deeper into the possibilities of re-engineering in the BIM context. This research presents one approach on how to merge these two theories and creates a process as well as a guideline for BIM implementation based on that.

The essential tools in the BIM implementation guideline are

- three evaluation indicators,
- visualization tool, and

- progress-scoring system that enable follow-up of implementation progress.

The novelty of this thesis is in its thorough evaluation stage, which includes the three evaluation indicators, as a first step in the implementation guideline. Other tools, which were mentioned previously in this paragraph, are not novelties, since their bases lie on the BIM framework, and they have only been modified to fit with re-engineering theory and the needs of the structural precast fabricators.

Regarding managerial implications, the framework has only been completed, and it represents concrete and visual plans and tools to carry out the BIM implementation efforts at structural precast fabricator companies. Hopefully, with the guideline presented in this study, structural precast fabricators are able to perform the BIM implementation efforts in a more efficient and controlled way. In addition, the tools that have been created as a part of this study offer a practical way to plan, execute and follow up on the BIM implementation efforts.

6.2. Assessment and limitations of the study

So far only the innovators and early adapters of the precast industry have implemented BIM in their processes. This means that the study could still help the majority of the industry to gain successful results from BIM implementation efforts. Thus it can be thought that the timing of the study was quite successful.

As BIM is a relatively new paradigm, there is not that much literature available and new literature, studies and research results are published on a monthly basis. The amount of research data on BIM was rather limited, which definitely presented challenges for the study. However, re-engineering is an older paradigm, and there was plenty of related data available, and as a paradigm, re-engineering is more a thing of the past than BIM. For this study, a research method was chosen that relies heavily on the researcher's experience, and this definitely limited the results of this study.

6.2.1. Reliability and validity

The two main questions to assess the quality of research are the reliability and validity of the results. Reliability means that if another researcher would use similar data collection methods, they would reach similar results and conclusions. Validity means that the data-collection methods used in the research measure what they were intended to measure and that the findings reflect what they claim to reflect.

According to Olkkonen (1994, p.27), it is hard to establish reliability in hermeneutic research, although this is a fundamental concept in research, and it should be defined. In hermeneutical research, reliability needs to be understood as the repeatability of the research when conducted by other researchers, since in hermeneutical research, it is not possible to obtain a quantitative figure (Olkkonen 1994, p.27). The data-collection methods used in this research, the literature reviews and case interviews, can be repeated by any researcher, and most of the results are repeatable, but in some parts of the results the author's knowledge was used to modify existing theory. Based on the above, it can be concluded that there are some questions concerning reliability, but their impact on the research is limited.

According to Olkkonen (1994, pp.38–39), quantitative examination of validity in hermeneutical research is hard and that is why it should be based on careful consideration and evaluation. However, the "*knowing nature*" and in-depth way of consideration helps maintain good validity in hermeneutical research (Olkkonen 1994, pp.38–39). Since either of the data-collection methods did not gather any quantitative results as the results received with the methods were more qualitative by nature, the validity of this research bases on the researcher's thorough personal evaluation of methods and findings.

6.2.2. Assessing achieving the objectives

To assess whether the study has reached its goals, let us review the research questions set in chapter 1. The main question was ”*How to make BIM implementation more efficient for the structural precast industry?”* and the three sub-questions were the following:

1. *What kinds of sub-phases enable an efficient implementation process?*
2. *What kinds of competencies are needed from individuals and organizations during the implementation?*
3. *How to follow up on the progress of implementation?*

Chapter 5.2 responds to the first sub-question and the results show that it mainly follows Succar's BIM framework, which is built on the five BIM Stages, which are then connected by four BIM Steps. Some phases were added to the process based on the literature review on re-engineering. The second sub-question was mainly considered in Chapter 5.4.4, and the notion was that the competencies should follow the principles of Succar's BIM framework, but the competencies needed some modification to fit into the context of this thesis. The last sub-question was mainly discussed in Chapter 5.5, and it also bases on Succar's BIM framework. A visual progress-monitoring tool and a simple progress-scoring system were created to make BIM implementation follow-up easier.

Figure 6.1 summarizes the empirical findings of this study regarding a BIM implementation guideline. Thus, it can be said that all research questions have been answered. The primary target was an easy and documented process to enable smoother implementation of BIM software at structural precast fabricator companies. The end result of this study was not an easy and documented process, but a guideline that helps evaluate, execute, and follow up on the structural precast fabricators' BIM implementation efforts.

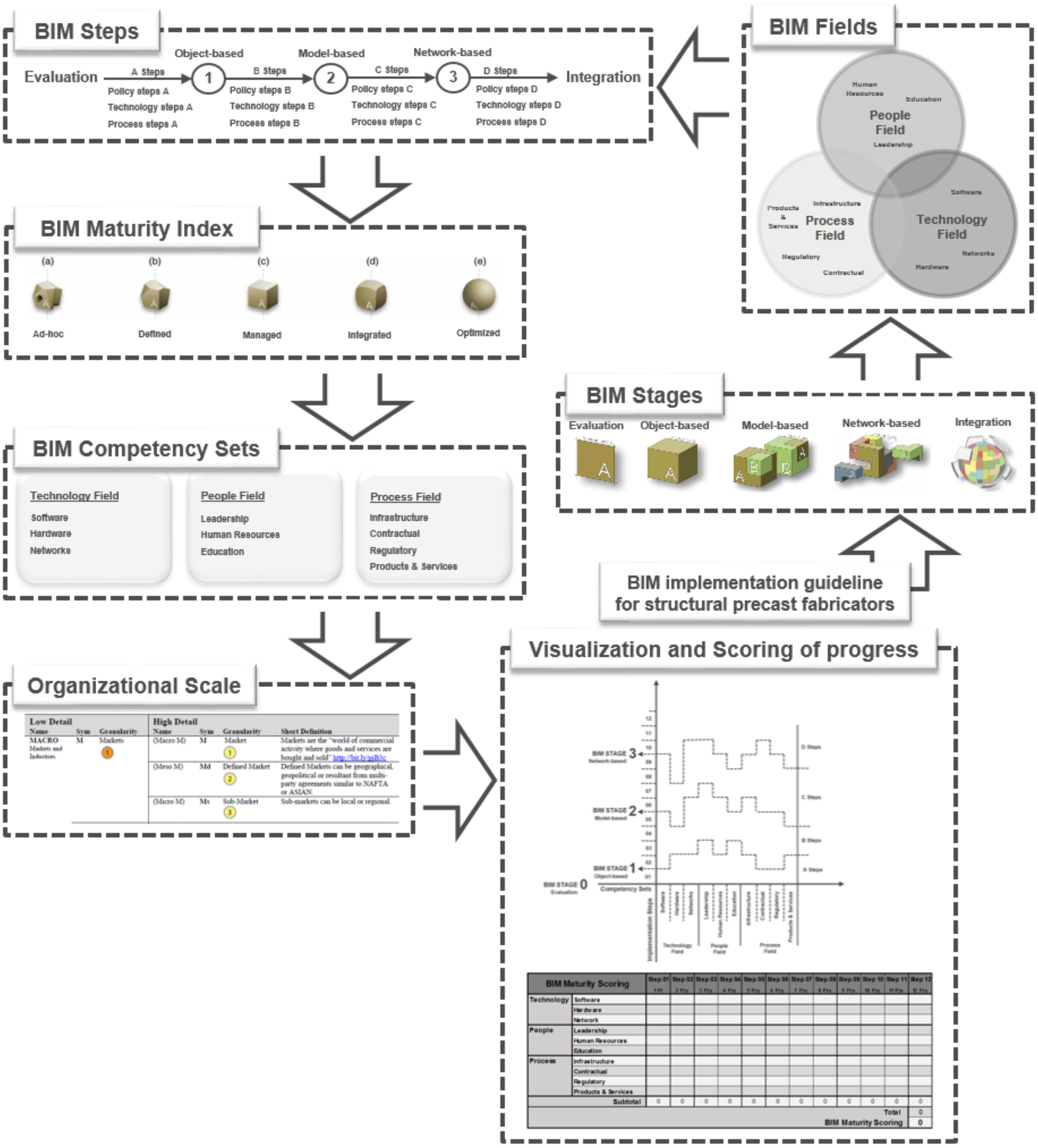

Figure 6.1 BIM implementation guideline for structural precast fabricators.

6.3. Future research themes

This final chapter discusses possible future research paths that were recognized during the course of the study. Firstly, testing of this BIM implementation guideline for all three category levels of structural precast fabricators that are mentioned in chapter 4.3 is needed, since the suggestions are based on literature reviews and the author's own experiences. Secondly, when this testing is performed, more specific documentation of the different phases of the implementation process as well as of the guideline is needed, especially regarding single task-level issues. Thirdly, since the bottlenecks of the current way of working were the starting point of the research, the bottlenecks of this BIM implementation guideline should also be analyzed during the testing.

Based on the findings of this study, change management plays a huge role in BIM implementation, and many academics as well as the industry experts compare BIM implementation to ERP implementation, which usually also requires many changes inside the executing companies. More studies regarding change management during BIM implementation are needed, and they, for instance, should take into account the various cultural differences that exist around the world.

This BIM implementation guideline was created purely based on the needs of structural precast fabricators. Construction industry includes several similar fabrication industries, and it would be good to test how this specific guideline for structural precast fabricators would fit structural steel fabricators or reinforcing bar fabricators, for example.

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APPENDIX 1: Case interview questions

Background data (situation before BIM implementation)

1. What were the main reasons to choose this specific software solution?
2. What kind of expectations did you have for the BIM implementation?
3. What kind of experience from software implementation your company had before implementing BIM software?

Experiences during the implementation

1. How did the implementation progress go and was there a clear plan for it?
2. How did software vendor handle your questions during the implementation and were they handled in appropriate time?
3. What do you think about the communication during the implementation?
4. How did the software vendor take care of the installations and trainings?
5. How did the software vendor support your company during the implementation?
6. How did the training, which was provided by software vendor, support your implementation?
7. What were the biggest challenges in the implementation?

Feelings after the implementation

1. How are you using BIM software at the moment and does it meet your requirements?
2. What did you learn from the implementation?
3. What do you think about your implementation's schedule?
4. How do you think you will use the BIM software in the future?
5. What kind of grade you would give to the implementation? (from 1 to 10 when 1 is the lowest and 10 is the best possible grade)
6. Would you recommend the BIM software based on your implementation experience?